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1951

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The Sea Lamprey in the Great Lakes

VERNON C. APPLEGATE

The author, who is in charge of the sea lamprey investigations of the Fish and Wildlife Service, U. S. Department of the Interior, joined the staff of Great Lakes Fishery Investigations in 1950. His present studies are in effect a continuation of researches begun in 1947 when he was employed as a fishery research biologist with the Institute for Fisheries Research, Michigan Department of Conservation. Earlier, Dr. Applegate was biologist with the International Pacific Salmon Fisheries Commission and teaching assistant in the Department of Zoology, University of Michigan, where he took his Ph.D. in 1950.

THE sea lamprey (*Petromyzon marinus*) is typically anadromous; that is, it hatches and spends its early life in fresh water, mi-rates to the ocean, where it grows to maturity, and turns to fresh water to spawn. It is during its life the ocean that it is parasitic on fish. Sea mpreys have long been known in the streams of ur Atlantic coast, where they have been taken as r south as northern Florida. In common with rtain other anadromous species, the sea lamprey as adjusted itself in some areas to spending its ntire life cycle in fresh water. It is native, for xample, in Lake Ontario and in some lakes of orthern New York.

Prior to the construction of the Welland Canal 1829, Niagara Falls stood as a barrier to the pread of the sea lamprey from Lake Ontario to e other Great Lakes. Even after the completion the canal, the lamprey seems to have been slow take advantage of the route, for the first specimen to be taken above the falls was captured in 1921, nearly a century later, in Lake Erie off Merlin, Ontario. It is possible, of course, that sea lampreys straggled through the canal repeatedly but were not seen or captured. The first known spawning population of the sea lamprey was discovered in 1932 in the Huron River, a tributary of Lake Erie.

The sea lamprey has never been able to establish itself in great numbers in Lake Erie, but, once it reached Lake Huron, its spread and increase in abundance were rapid. Well before the end of the 1930s Lake Huron fishermen began to complain of the increasing frequency of scarred lake trout in their catches and the deterioration in the quality of lake trout fishing. They expressed a grave fear that this parasite might completely destroy the fishery for the species.

That this fear was well grounded was borne out by subsequent experience. The speed and the completeness of the collapse of the lake trout fishery in Lake Huron are demonstrated by the record (Table 1) of the catch in United States waters from 1935 through 1949. The production figure for every year after 1939 set a new record low.

The first sea lamprey known to have been captured in Lake Michigan was taken off Milwaukee in 1936. The rapid increase in abundance of the sea lamprey and the decline of the lake trout got under way later in Lake Michigan than in Lake Huron, but aside from this difference of timing the trends have been much the same. How similar the course of the decline of the lake trout fishery in the two lakes has been is evident from the comparisons of the record of production in Lake Michigan with that for the same years in Lake Huron (Table 2). In Lake Michigan the series of record-low years began with 1947.

A few individuals not acquainted with the trends of the lake trout fishery have suggested that the catastrophes that have overtaken Lake Huron and Lake Michigan were the result of overfishing, and hence that the present distress of the industry is but just retribution for a wanton and destructive exploitation of the stocks. Complete and detailed statistics, beginning with 1929, on the actual quantities of gear lifted that produced lake trout demonstrate conclusively, however, that overfishing could not have brought about the collapse in the lake trout fishery in the United States waters of Lake Huron or in the state of Michigan waters of Lake Michigan. Fishing pressure in both areas tended to be below the modern average in the years immediately preceding and during the recent decline. The outside possibility that some obscure and altogether unsuspected factor may have destroyed the lake trout populations of Lakes Huron and Michigan cannot be ignored, but the most careful consideration of available evidence nevertheless permits only one conclusion—namely, that the sea lamprey was the major, perhaps the only signif cant, cause of the decrease of the lake trout i both lakes.

TABLE 1

Year	Pounds
1935	1,743,000
1936	1,400,000
1937	1,340,000
1938	1,270,000
1939	1,372,000
1940	940,000
1941	892,000
1942	728,000
1943	459,000
1944	363,000
1945	173,000
1946	38,000
1947	12,000
1948	4,000
1949	1,000

TABLE 2

Year	Pounds
1935	4,873,000
1936	4,763,000
1937	4,988,000
1938	4,906,000
1939	5,660,000
1940	6,266,000
1941	6,784,000
1942	6,484,000
1943	6,860,000
1944	6,498,000
1945	5,437,000
1946	3,974,000
1947	2,425,000
1948	1,196,000
1949	343,000

At prevailing market prices the actual loss c cash income to the commercial fishermen of Lake Huron and Michigan resulting from the decrease in the take of lake trout amounts to approximate $3,500,000. At a 4 per cent interest rate this figu represents the annual return from a capital in vestment of $87,500,000. When one considers ho greatly the decrease of income to wholesalers an retailers of fish, to transportation companies, and manufacturers of fishing equipment and suppli adds to the above value, and remembers also th no estimate is included for species other than la trout that have been harmed by the sea lampre the real gravity of the economic losses and t urgent need of sparing no effort to bring the par site under control become even more obvious.

The sea lamprey was first reported from La Superior in 1945. Although specimens have bee taken as far west as Minnesota, and spawning ru have been discovered as far west as Marquett Michigan, lampreys have become plentiful on in the extreme eastern end. Any effects on the la trout fishery, therefore, have been only local. Co respondingly, the production of lake trout in La Superior has held up, as statistics for United Sta waters prove (Table 3).

We should not be too ready to take comfort fro these production figures for Lake Superior, fir because records prove that the catch per net declining, and the yield has been maintained in cent years only by greatly increased fishing pr sure, and, second, because experience in La Huron, and especially in Lake Michigan, pro that complete collapse of a fishery can take pla in only a few years.

In both Lake Huron and Lake Michigan attacks by sea lampreys on other species increas s the numbers of lake trout decreased. Although e injury to stocks so far has not been as great for ther fish as for lake trout, the damage to some arieties, particularly whitefish, suckers, and wall-yes, obviously is heavy and is increasing to an larming extent in some waters. Seemingly all ommercial species are subject to some lamprey epredations.

Life History of the Sea Lamprey

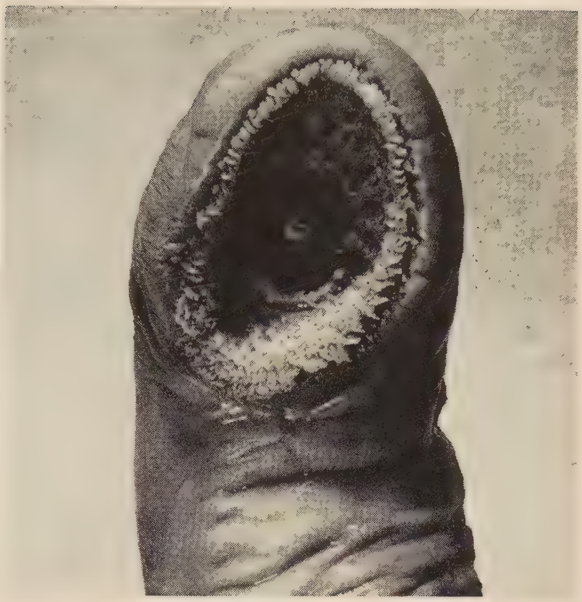
Knowledge of the enemy is essential to the aging of a successful war; hence, information on e natural history of the sea lamprey is vital if e are to ascertain the vulnerable points in its life ycle. During the past several years researches onsored by the state of Michigan and, more re-ently, by the Fish and Wildlife Service have added reatly to our information on this parasite. The llowing account is based largely on these in-estigations. For purposes of description the life ycle may be divided into two periods—stream life nd lake life.

Mature sea lampreys enter the streams tributary o the Great Lakes for the purpose of spawning in te spring and early summer. This spawning mi-ration extends over as many as sixteen weeks. emperature is a major controlling factor over e upstream movements; heavy runs do not begin ntil the stream temperature reaches 50° F. If the mperature drops below that point, the run slacks f. There is evidence that lampreys are unable to awn in streams that are too cold. They may enter em but they later return to the lake to seek an-her stream.

For successful nest building the sea lamprey re-uires a bottom of coarse gravel and rubble in an ea with a moderately strong current. Seizing ones with their suckerlike mouths, the sea lam-reys build crescent-shaped nests. If the grounds e extensive in relation to the size of the spawning population, the nests usually are well spaced within the stream. If the grounds are congested, the nests are closely grouped, and on occasion portions of the spawning areas are reworked by late arrivals.

TABLE 3

Year	Pounds
1935	3,476,000
1936	3,234,000
1937	3,085,000
1938	3,167,000
1939	2,744,000
1940	2,677,000
1941	2,854,000
1942	2,959,000
1943	3,053,000
1944	3,740,000
1945	3,369,000
1946	3,444,000
1947	2,964,000
1948	2,954,000
1949	2,965,000



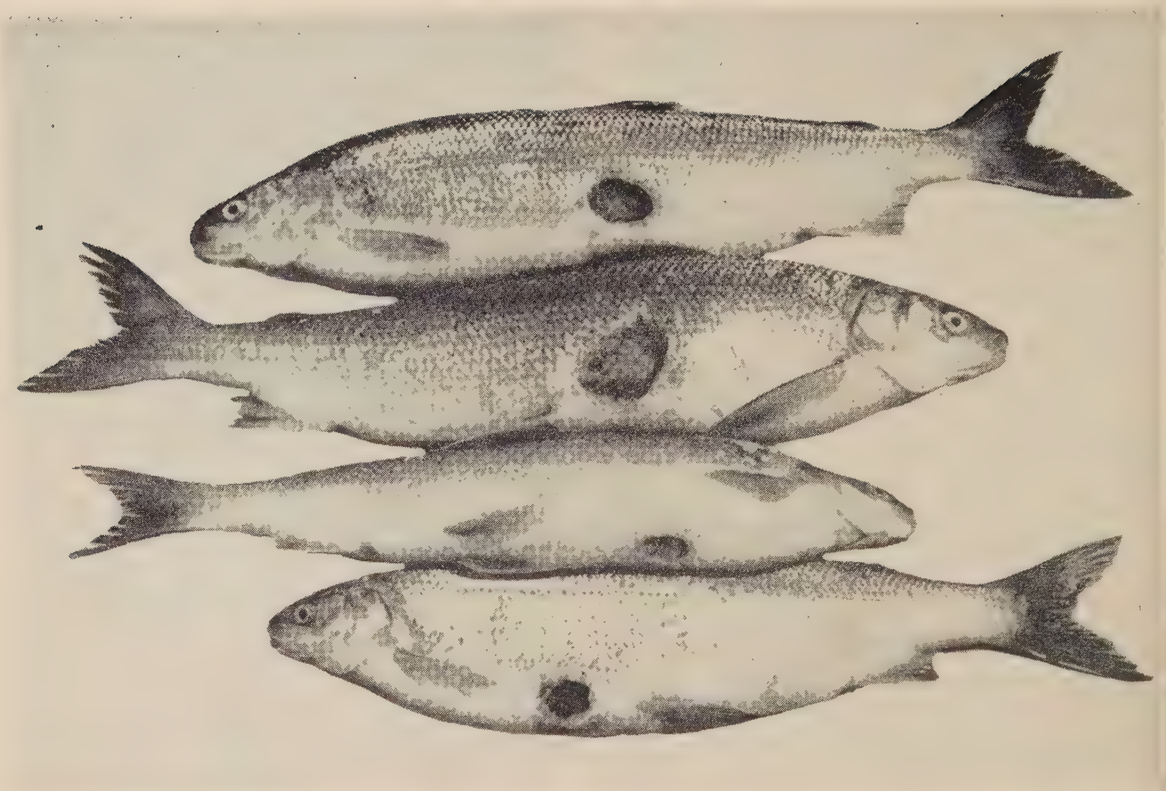
U. S. Fish and Wildlife photo

Mouth of sea lamprey of the Great Lakes.

When the eggs are extruded by the female and fertilized by the male, they are carried by the current into the gravel of the nests, where they develop and hatch in ten to twelve days, depending on temperature conditions. A single female may deposit as many as 107,000 eggs; the average number is about 61,500. The sea lamprey spawns only once. All adults die soon after they complete spawning.

When the recently hatched larvae emerge from the nest, they drift downstream until they reach mud and silt flats. Here they dive for the bottom, where each establishes itself in its individual burrow. The food, which is sucked in from the water passing the mouth of the burrow, consists largely of microscopic organisms that live in the surface film of the stream bottom. During the stream life the young lampreys are completely harmless. According to our best evidence, the length of the larval life is about four years. During the final season in the stream the larvae begin to transform into the adult parasitic stage. Once the transformation is completed, they emerge from the mud flats and drift lakeward.

The newly transformed larvae range from 3.7 to 7.2 inches long and average 5.7 inches. The downstream movement always occurs at a time of rising water levels. Some of the young lampreys leave the streams in the late fall, and a few migrate



Four lamprey-scarred whitefish taken by a commercial fisherman in northern Lake Huron.

at various times during the winter, but the major downstream movement occurs at the time of breakup in the spring. When the young sea lampreys reach the lake they are ready to begin their parasitic existence.

During the parasitic phase of its life, the sea lamprey feeds on the blood and body juices of fish. It attaches itself to its victim by means of its sucker-like mouth and with its sharp teeth rasps a hole in the body. Lampreys kept in aquaria will remain attached to fish as long as three weeks, provided the victim does not die. These same aquarium experiments proved that delicate species such as the brook trout are killed quickly, but that more hardy fish such as bullheads may survive attacks by several lampreys over a period of weeks.

Details on the life of the sea lamprey in the lake are scanty. Measurements of a considerable number of specimens indicate that the average time in the lake is about one and one half years. (An experiment currently in progress, on rearing sea lampreys in aquaria, supports this estimate.) There is some evidence also that the newly transformed sea lampreys migrate first to deep water, where they attack lake trout, chubs, and other deep-water species. As the lampreys grow larger,
they move shoreward and in the fall are to b
found in relatively shallow water. It is at this tim
that attacks on whitefish, suckers, and other sha
low-water fish reach their maximum.

Toward the end of winter and in early sprin
the sea lampreys begin to congregate in estuari
off the mouths of streams. During this waitin
period preceding the spawning migration, tr
mendous internal changes occur. The sex glan
expand enormously, and the digestive tract an
other organs shrink. As a result of these chang
the lamprey becomes incapable of feeding. Th
process of deterioration extends even to the mu
culature and skin. At the time of this general brea
down the lamprey is subject to extensive attac
by fungus.

Program for the Control of the Sea Lamprey

According to the present state of our knowledg
the most vulnerable period in the sea lampre
life cycle occurs in the stream. Attacks on lam
preys in the streams have been organized alo
three lines: prevention of spawning through th
blocking of the stream and/or the capture an
destruction of lampreys en route to the spawnin
grounds; the destruction of larval lampreys befo

y emerge from the mud and silt flats; the de- ıction of the newly transformed migrants en te to the lake. Of the three approaches, the first l third appear to offer the greatest promise. It ıevertheless planned to develop and test pro- ures along all lines. Nothing that has even an side chance of yielding positive results will be ored.

revention of spawning. Tests are in progress or nned on a variety of weirs, traps, barrier dams, l sonic and electrical devices as a means of cap- ing or destroying spawning-run sea lampreys of preventing their movement upstream. In ny streams this type of operation is handicapped erely by the necessity for avoiding injury to ıs of such valuable food and game fish as suck- , northern pike, walleyes, and rainbow trout. is limitation makes it impossible, for example, apply electrical charges that might prove lethal lampreys, or to bar passage upstream unless ıipment can be developed that will block or the lamprey without blocking or greatly in- ing fish. Similarly, weirs need to be equipped h traps so that fish can be passed up- or down- eam while the lampreys are removed and de- oyed. Barrier dams need similar traps unless y can be so constructed that they will block the lampreys but are still low enough to be jumped by fish.

Devices that prevent the spawning of sea lampreys offer a positive method of attack, but they have one great drawback—the tremendous cost of installation and operation in the many scores of streams that contain lamprey runs. The installation of weirs in small streams is not extremely expensive, but the larger weirs cost many thousands of dollars. Furthermore, these structures require regular and frequent attention and service if they are to be operated efficiently. A second difficulty with control based on the blocking or destruction of spawning-run sea lampreys lies in the circumstance that the benefits from these activities are long deferred. Since the larval life is approximately four years long, and the length of the parasitic phase averages approximately eighteen months, results from the blocking of runs cannot become apparent until more than five years have elapsed.

Destruction of larval sea lampreys. The destruction of the larval lampreys offers the advantage that as many as four generations of young can be eliminated at one time and results can accordingly be expected in less than two years. The practical difficulties, however, are enormous. In most waters the larval beds are widely scattered throughout

Sea lamprey weir in the Ocqueoc River, a tributary of northern Lake Huron. The cost of constructing this weir $13,000; annual expenses for maintenance and operation amount to about $4,000.

the stream. Some of the larger beds can be attacked, but the lampreys settle down in such small patches of silt (as those commonly to be seen on the downstream side of deadheads) that to locate and treat all of them is not feasible. Because of this wide scattering the mechanical destruction of larval lampreys in silt beds does not seem practicable. Killing by electrical current has been considered, but the results with equipment tested to date have not been promising. The chemical treatment of larval beds offers some promise if we can solve the problem of poisoning the lampreys without making the stream water so toxic as to be lethal to fish. Experiments on the reactions of larval sea lampreys to various toxicants are now in progress.

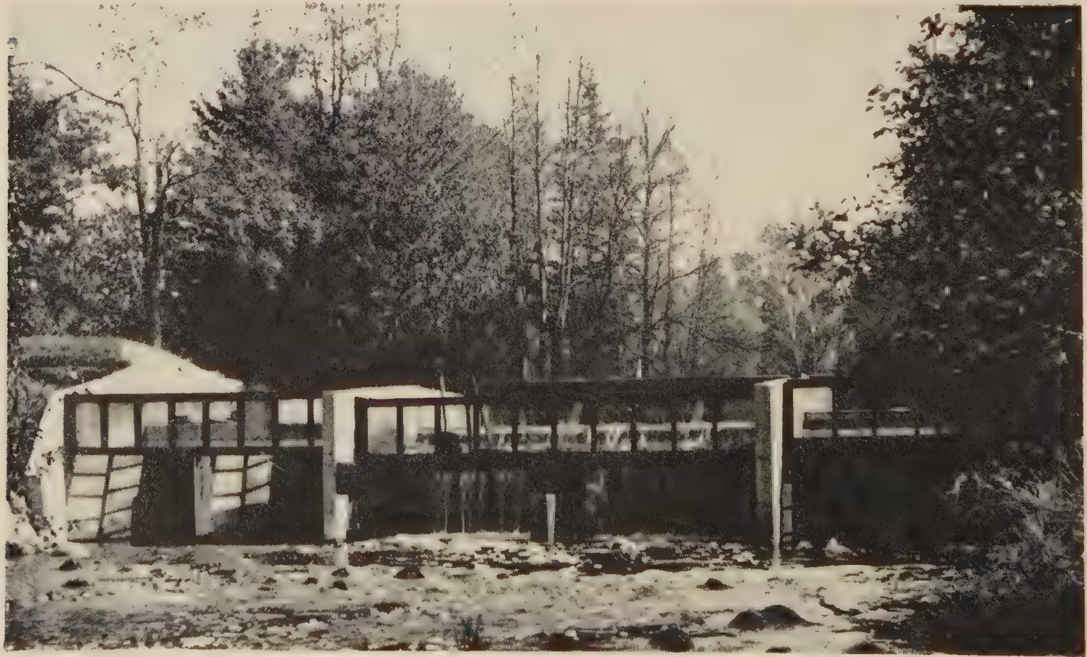
Thought has been given also to the possibility of introducing animals that might prey on larval sea lampreys. In this connection the American eel gives some promise. Tests conducted in aquaria have demonstrated that eels will attack and destroy larvae, but whether similar results can be obtained under natural conditions remains to be determined. It is important also to make certain that any eels that might be introduced will not prove harmful to native fish.

Destruction of newly transformed sea lampreys. The downstream migration of newly transformed larvae in the winter constitutes a period in the life cycle of the lamprey which offers even greater possibilities for destruction than the time of tl upstream spawning migration. At this time of ye the movements of fish are at a minimum. Cons quently, equipment that kills any organisms passir along the stream inflicts only negligible dama on animals other than lampreys.

Experiments have demonstrated that dow stream migrants can be taken readily by means a dam and inclined-screen trap, but this equi ment is expensive to construct and requires regul attention. Furthermore, the topography of mai streams does not lend itself to this type of structu Far more promising are electrical installatio that send a current through the stream sufficient strong to kill the lampreys as they drift by. A tention is being concentrated on the developme of apparatus that will give the greatest effectiv ness at minimum cost. These devices must be constructed as to be safe and to need only occ sional inspection and service. Preliminary expe ments have indicated that young lampreys a extraordinarily resistant to electrical currents, th the construction of a lethal device will be mu more difficult than was anticipated, and that t operation may prove prohibitively costly.

The Outlook for Control

Biology, engineering, and economics—all of th must enter into our consideration when we spec late as to the possibility of developing a progr



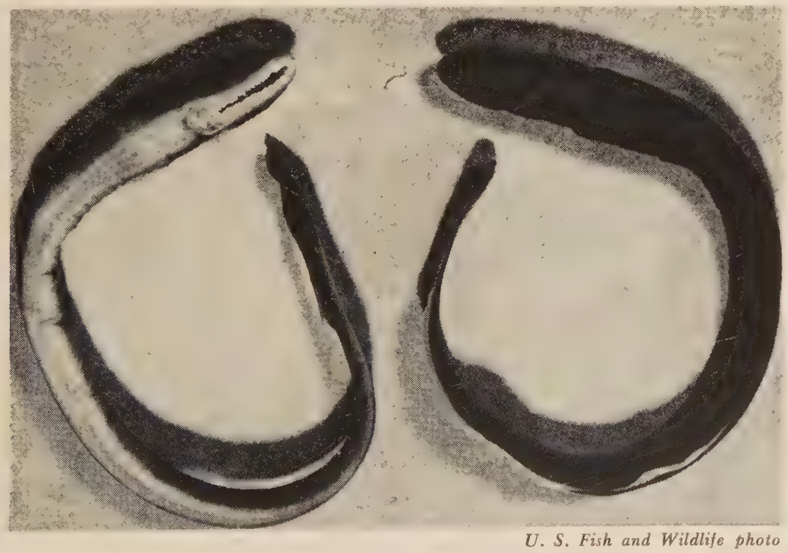
Inclined-screen trap at a dam in the Carp Lake River, a tributary of the Straits of Mackinac. This device pr effective in trapping the downstream runs of young, recently transformed sea lampreys. The aggregate cost of the and trap was about $6,000; annual maintenance and operation costs are about $3,000.

Removing spawning-run sea lampreys from a weir-
p in the Ocqueoc River.

the effective control of the sea lamprey in the
per Great Lakes. The available information on
e life cycle of the sea lamprey is sound and suf-
iently extensive to serve as a basis for the initiation of control procedures. Certain aspects of the predator's natural history need to be explored further so that we may judge better the most vulnerable points in its career. Only through more detailed knowledge is the maximum efficiency to be obtained.

Economic considerations dictate that no effort be spared to accomplish the greatest destruction of sea lampreys at the least cost. If cost were no object, control might easily prove to be relatively simple. However, a control program that could be maintained at an annual figure approximating or exceeding the potential value of the fisheries could not be termed sound. Major effort is to be directed, therefore, toward the development of more and more destructive devices that will call for less and less expense in installation and maintenance. The success or failure of attempts to control the sea lamprey well may be determined by the success or failure in the development of procedures the cost of which can be economically justified. There can be little doubt that the most effective control of the lamprey will be accomplished by a variety of procedures, each adapted to serve best under special local conditions.

Control of the sea lamprey will not be accomplished either in a short time or easily or cheaply. Furthermore, the control measures will need to be established on a continuing basis. The prospects for the eradication of this predator are so meager that they should not enter into our consideration in setting up a control program. We cannot hope for an immediate solution of the sea lamprey problem and a rapid return of the fisheries to their former productivity.



U. S. Fish and Wildlife photo

Newly transformed sea lamprey, taken in weir on the Ocqueoc River, on its way to Lake Huron to begin parasitic existence.

SEA LAMPREY INVESTIGATIONS

II. EGG DEVELOPMENT, MATURITY, EGG PRODUCTION, AND PERCENTAGE OF UNSPAWNED EGGS OF SEA LAMPREYS, *PETROMYZON MARINUS*, CAPTURED IN SEVERAL LAKE HURON TRIBUTARIES *

VERNON C. APPLEGATE

INTRODUCTION

THIS study constitutes the second of a series of reports which embody the findings and results of investigations begun early in 1947 by the Michigan Institute for Fisheries Research on the life history and habits of the predatory sea lamprey. These investigations were initiated and are being carried on in an effort to provide a sound biological basis for any proposed method of reducing or controlling the numbers of this dangerous fish parasite in the upper Great Lakes. The first report of this series deals with the distribution of sea lamprey spawning populations in Michigan streams.[1] The present account is concerned primarily with the biotic potential of this fish. Subsequent studies will delineate other phases of the life history.

All field observations upon which this study is based were made between April 9 and July 10, 1947, on the Ocqueoc River and Carp Creek, Presque Isle County, Michigan. These dates are each within several days of the extreme time limits of the sea lamprey spawning migration into these streams. The peak of the migration occurred during the second week in June. In Carp Creek a weir and a trap were operated, and the entire sea lamprey run, 1,617 individuals, was captured. All these speci-

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* Contribution from the Institute for Fisheries Research of the Michigan Department of Conservation. Some financial assistance in this project was contributed by the Associated Fishing Tackle Manufacturers' Trust Fund for Fisheries Research in the University of Michigan.

[1] Applegate, Vernon C., "An Inventory of Spawning Streams of the Sea Lamprey, *Petromyzon marinus*, in Michigan," *Mich. Inst. for Fish Res., Tech. Rept.*, No. 1 (forthcoming).

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mens were examined at capture by the writer. In the Ocqueoc River the spawning migration was unimpeded, but large samples of the migrants were obtained and examined. The entire ovaries were removed from seventy migrant females and preserved in F-A-A (a solution of formalin, acetic acid, and alcohol). Fifty-eight of these specimens were taken in Carp Creek, eight in the Ocqueoc River, one in Ocqueoc Lake (in a gill net, presumably while migrating through the lake to the spawning grounds in the river upstream from the lake), and three were captured in the Cheboygan River below the power dam in the city of Cheboygan, Cheboygan County. Pertinent mensural data were collected on all specimens at the time of capture. The specimens utilized were deliberately selected for length so that all size groups in the migrant population would be adequately represented among the data. To obtain a better measure of the variability in egg production at a given size additional specimens were collected in the 17.0–18.0-inch (432–457 mm.) size group. This group embraces the mean length (17.4 inches, 442 mm.)[2] of the 603 females which entered Carp Creek in 1947.

The earliest specimens represented in my series of seventy migrant females (Nos. 1, 2, and 3) were speared just before midnight on April 15, and on April 16, in Hammond Bay, about one hundred feet offshore from the mouth of Carp Creek. They undoubtedly represent the earliest migrants arriving from deeper waters of Lake Huron as determined by repeated observations during the period April 9 through April 15. Those observed were making no effort to enter the creek at that time. They arrived on the gravel fan off the mouth of the creek about two hours after dark and dropped back into deeper water with the beginning of dawn. Upstream migration began on or about April 19. After April 15–16 specimens for this stuly were collected at five- to ten-day intervals throughout the migratory period.

In addition to the gravid females, forty spent and dead or dying specimens were collected in the Ocqueoc River, the Little Ocqueoc River (a tributary of the former), and in the Manistique River (a tributary of Lake Michigan), Schoolcraft County (one specimen). The remnants of the ovaries and all eggs remaining in the body cavity were removed and preserved in F-A-A.

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[2] The data from which certain averages mentioned in this report are derived will be discussed in detail in a subsequent report.

EGG DEVELOPMENT AND MATURITY IN SPAWNING MIGRANTS

Female sea lampreys, when sexually mature and ripe, have a single elongate ovary extending nearly the entire length of the body cavity (Pl. I). The anterior tip of the ovary begins just behind the last pair of gill pouches, and the organ extends posteriorly to the anus. The ovary, when the eggs are ripe, or nearly so, constitutes a large percentage of the total weight of the female. In eighteen ripe or nearly ripe females collected between June 12 and June 26 the ovaries averaged 22.4 per cent of the total weights of the females and ranged from 13.6 to 29.5 per cent. On the other hand, in eight less mature females collected between April 15 and April 30, at the beginning of the run, the ovaries averaged only 11.3 per cent of the total weights of the females and ranged from 8.2 to 15.8 per cent.

When the eggs are fully ripe, they are shed into the coelom (body cavity) and are forced to the exterior during the spawning act through a pair of genital pores. One of these pores enters each side of the urogenital sinus, which is provided with a median pore to the outside on a papilla situated behind the anus. No Müllerian ducts (nor *vasa efferentia* in the male) are present, unless the paired pores represent them. The ripe eggs are spherical to pear-shaped in form and sandy to light tan in color. At the time of extrusion they are nonbuoyant and somewhat adhesive; sand grains stick to them readily.

In order to determine the nature of the ova present throughout a given ovary and the degree of egg development (i.e. stage of maturity) in females at different times during the spawning run, diameter measurements of ova were taken from eight specimens. They were made by means of an ocular micrometer in a compound binocular microscope; calibration of the ocular micrometer with a stage micrometer indicated a value of 0.05 mm. for each micrometer unit; diameters were therefore determined to the nearest 0.05 mm.

Owing to the effects of preservation and the natural shape of many of the eggs, very few were perfectly symmetrical. In order to avoid any selection of the longest or shortest diameter the micrometer was fixed in a vertical position upon the field of vision, and the diameter parallel to the graduations on the micrometer was measured. This gave the longest diameter of some eggs, the shortest of others, or intermediate measurements between the two. Clark (1925) tested this method and found it to be reliable. It was used again by the same author (Clark, 1934) and by Carbine (1944) with excellent results. Although the eggs appeared equally turgid and well formed both after preservation and when examined fresh, I do not know if any small shrinkage occurred because of preservation. If any did occur, it could hardly have been an appreciable amount. In any event, the relative values obtained would keep their identity.

The first ovary analyzed was from a 12.6-inch (320 mm.) female taken in the Carp Creek weir on June 16, 1947. The weight of this female was 70 grams, and the ovary weighed 13.50 grams or 19.2 per cent of the weight of the specimen. Sections were removed from the anterior, middle, and posterior thirds of the ovary. The eggs were teased out of the sections, a random sample of 500 eggs was obtained, and these eggs were measured. A frequency diagram of these ovum measurements appears in Figure 1. For each section the average diameter and range were as follows:

Section	*Average diameter*	*Range*
Anterior	0.87 mm.	0.35–1.10 mm.
Mid	0.90	0.50–1.15
Posterior	0.82	0.35–1.15

It is apparent from these data that the ova in the midportion of the ovary are slightly larger than those developing in the front and back portions. The difference is so small, however — 0.03 mm. and 0.08 mm. — that no appreciable error is involved in the other measurements and calculations made from midsections only.

Jordan (1905) reported that "A. Mueller, in 1865, showed that all the ova in the lamprey were of the same size, and that after spawning, no small reproductive bodies remained to be developed later." It is not quite clear to which species he has reference. In the light of the examination of this and subsequent specimens of the sea lamprey, this statement is in need of qualification. Three categories of ova were present in the material examined. First, there are the developing ova (represented by the highest modes in Figure 1). These are by far the most numerous in the ovary and are the eggs which are destined to be spawned very shortly. Second, there are ova of apparently retarded development which I term "partially developed ova" (these are represented in Figure 1 by each low mode to the left of the high ones representing the developing ova). The partially developed ova are scattered throughout the ovary and differ from the larger ones only in size and amount of contained yolk; the form appears similar. Such eggs are present in variable numbers in all females,

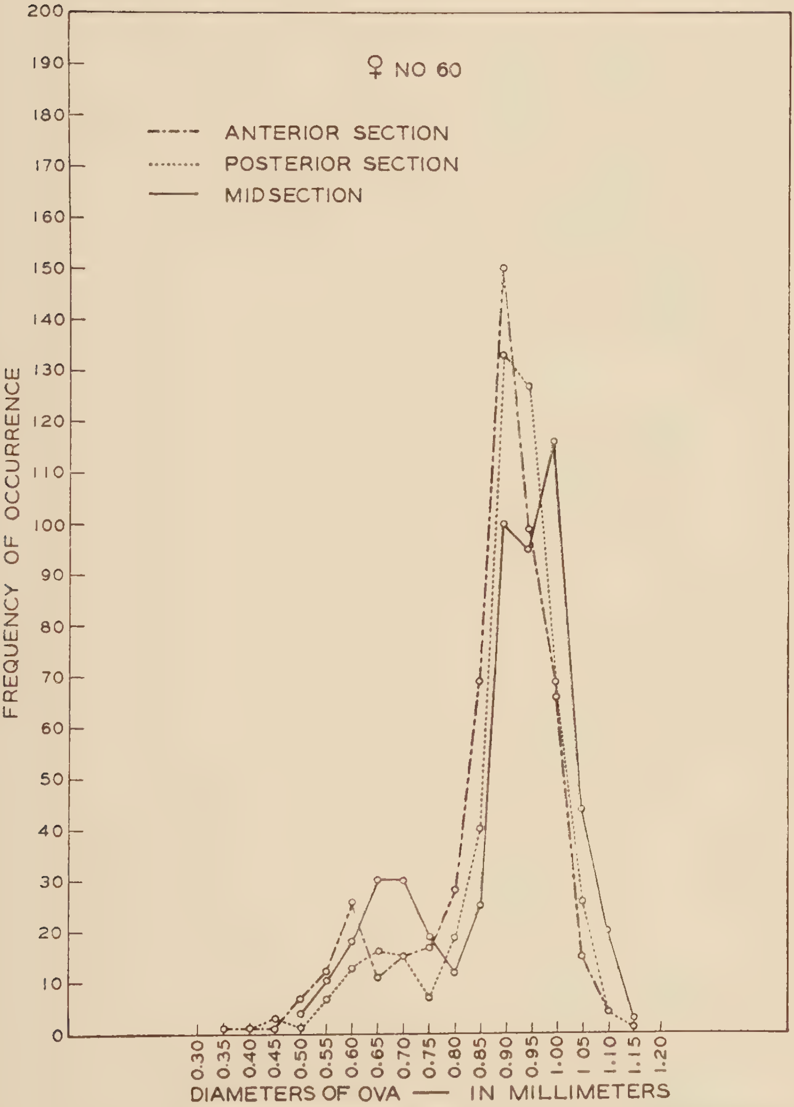

Fig. 1. Frequency distributions of ovum diameter measurements made from samples taken from the anterior, mid, and posterior sections of the same ovary

but are more commonly found in the smallest specimens and are quite infrequent in the larger ones. The individual represented in Figure 1 is believed to have contained the largest number of partially developed ova in the entire series studied. It probably represents the greatest proportion of this kind of eggs present in the females of an average spawning run. In examining females in which the eggs had burst into the coelom I found that some of these retarded ova are extruded with the fully developed ones. The majority, however, remain trapped in the remnants of the ovary. Other experiments have shown that those that are extruded with the mature ova can become fertilized, but it is not known whether full development to hatched larvae occurs. Ova in the third category are microscopic in size, generally between 0.20 and 0.30 mm. in diameter. They are variable in number in different females, but as a rule they are quite numerous, although their total number is always less than that of the more mature eggs. These ova, unlike those of the other two categories, are translucent, contain little or no yolk, and are still firmly attached to pedicels in the gonad. Since they could readily be found only in the frayed ovarian tissue of spent females, they do not enter into any of the measurements or counts that were made. They were too small to be seen with the magnification used in making the counts and measurements of the other two kinds of eggs. It seems logical to conclude either that mature ova of the sea lamprey develop at the expense of the retarded and undeveloped ones or that some mechanical impediment aborts the development of the latter; both probably occur. I do not believe that either of these categories could be construed to represent a potential reserve stock that would enable the female to spawn again in the following year.

Jordan (1905) further states that ". . . the most careful microscopical examination of ovaries or testes has failed to reveal any evidence of new gonads or reproductive bodies." My preliminary examinations seem to confirm this. Even if it should be demonstrated that the ovaries or testes of some spent sea lampreys contain spermatogonia (and spermatocytes) or oögonia (and oöcytes), the presence of such germ-cell stages need not necessarily indicate that these specimens would have lived to spawn in another season. Weisel (1947) has shown the presence of these germ cells in spent, landlocked sockeye salmon (*Oncorhynchus nerka*) of both sexes. Individuals of this species become sexually mature and spawn only once, dying very shortly thereafter. Weisel concluded that some factor, other than a potential supply of germ cells, limits the spawning of this Pacific salmon to a single season.

In general, the developmental stages of the ova found in the sea lamprey are similar to those found in other fishes that spawn during a single brief period, that is, the maturing eggs constitute a single size group more or less discrete from the immature ova. The sea lamprey, however, differs fundamentally from such fishes in one respect. In females of those species that spawn in several or many seasons the immature eggs greatly outnumber the maturing eggs at the time of spawning (Carbine, 1944). It is here demonstrated that in the sea lampreys studied the maturing eggs outnumbered the undeveloped ones present. This fact, the absence of any germ-cell stages, and the nature of other physiological changes at spawning I consider very strong evidence that the sea lamprey spawns but once and then dies.

Ovum diameters were obtained from seven additional specimens. Six of these were selected from the series available, so that one of the earliest and one of the latest migrants and four migrants taken on scattered intervening dates were represented. For uniformity these were selected to fall within 17.0 and 17.5 inches (432 and 445 mm.) in total length. These factors alone governed the selection of the specimens. A seventh specimen (No. S-41) of comparable length (16.4 inches, 417 mm.), taken on the spawning grounds, was chosen for examination, since in this female the bulk of the eggs had burst into the coelom and presumably represented fully mature eggs. The data for six specimens are based on sample sections removed from the previously described midregion of each ovary. These samples were teased apart, and a randon sample of 500 ova from each was measured. For specimen No. S-41 a random sample of 500 ova was taken from the total number that were loose in the coelom. The data obtained for all seven specimens are presented in Table I, and those for six of the specimens (including No. S-41) are graphically portrayed in Figure 2.

Ova among the earliest spawning migrants entering a stream are about three fourths of a millimeter in diameter (average, 0.75 mm.; range, 0.40–0.85 mm.). Fully mature eggs average about 1.10 millimeters in diameter and range from 0.80 to 1.25 millimeters. Migrants entering the stream on progressively later dates demonstrate progressively more advanced stages of egg development (Table I). It should be pointed out, however, that the smooth progression of increasing average ovum diam-

TABLE I

Diameter of Developing Ova in Seven Female Sea Lampreys Collected at Intervals during the Spawning Migration

Specimen number	Place of collection	Date of collection	Total length (inches)	Total length (in mm.)	Weight (grams)	Condition of ovary	Ovum diameters (in mm.)*	
							Average	Range
2	Hammond Bay — off mouth of Carp Creek	April 16, 1947	17.2	437	222	Green	0.75	0.40–0.85
4	Carp Creek weir	April 25, 1947	17.2	437	134	Green	0.76	0.50–0.95
14	Carp Creek weir	May 12, 1947	17.2	437	165	Green	0.83	0.40–1.00
23	Carp Creek weir	May 25, 1947	17.5	445	168	Green	0.91	0.45–1.10
36	Carp Creek weir	June 10, 1947	17.2	437	246	Green	0.98	0.45–1.20
73	Carp Creek weir	July 2, 1947	17.0	432	178	Ripe	1.03	0.60–1.25
S-41	Ocqueoc River	June 28, 1947	16.4	417	203	Eggs loose in coelom	1.10	0.80–1.25

* Range and averages for each specimen based on random sample of 500 ova taken from the midsection of the ovary.

eters with later dates of capture in Table I is most likely fortuitous. In examining nearly a thousand females I found that many degrees of maturity were represented among the specimens taken on a single day, particularly in midseason. The mean values listed in Table I are considered to represent the *average* degree of egg development in females entering the stream on the dates indicated.

In migrants entering the stream in mid-April 68.4 per cent of the development of the ova had still to take place while the female was in the stream (computed on the basis of the relative volumetric proportions of individual ova with the assumption that they are perfectly spherical). In females that entered the stream from mid-June until the end of the run the eggs were very nearly fully developed, but not so far along as to have burst into the body cavity. In only a few of the late migrants, including the last ones taken in July, were any eggs found in the coelom.

In the frequency polygons presented in Figure 2 a uniform horizontal scale was used for all six projections. Thus the relative degrees of maturity of the specimens examined is apparent in the progressive shifting of the frequency distributions from left to right. Of particular interest is the great scarcity of partially developed eggs found in most of the samples represented.

EGG PRODUCTION

Of the 70 specimens utilized to determine egg production, actual numerical counts were made of the ova in 10 specimens. These include the largest (21.1 inches, 536 mm.) and the smallest (12.6 inches, 320 mm.) females in the series and eight of intermediate size. Prior to making each of these counts, the total volume and the total weight of the ovary were obtained. A sample section was removed from the middle of the length of the ovary, and the volume and weight of the sample were likewise determined. Volumes were secured by a system of displacement of water into a cylinder bearing 0.2 cc. graduations and were read to the nearest 0.1 cc. Weights were obtained to the nearest 0.01 gram on a chemical balance. Excess moisture was removed as consistently as possible from all ovaries and sections before any determinations were made. Eggs in the sample section were counted first, and the total production was computed by direct proportion for both the volumetric and the gravimetric data. When the balance of the ova had been counted, the calculated totals by both techniques could be compared for accuracy. This procedure was followed for all ten specimens and the results are incorporated in Table II.

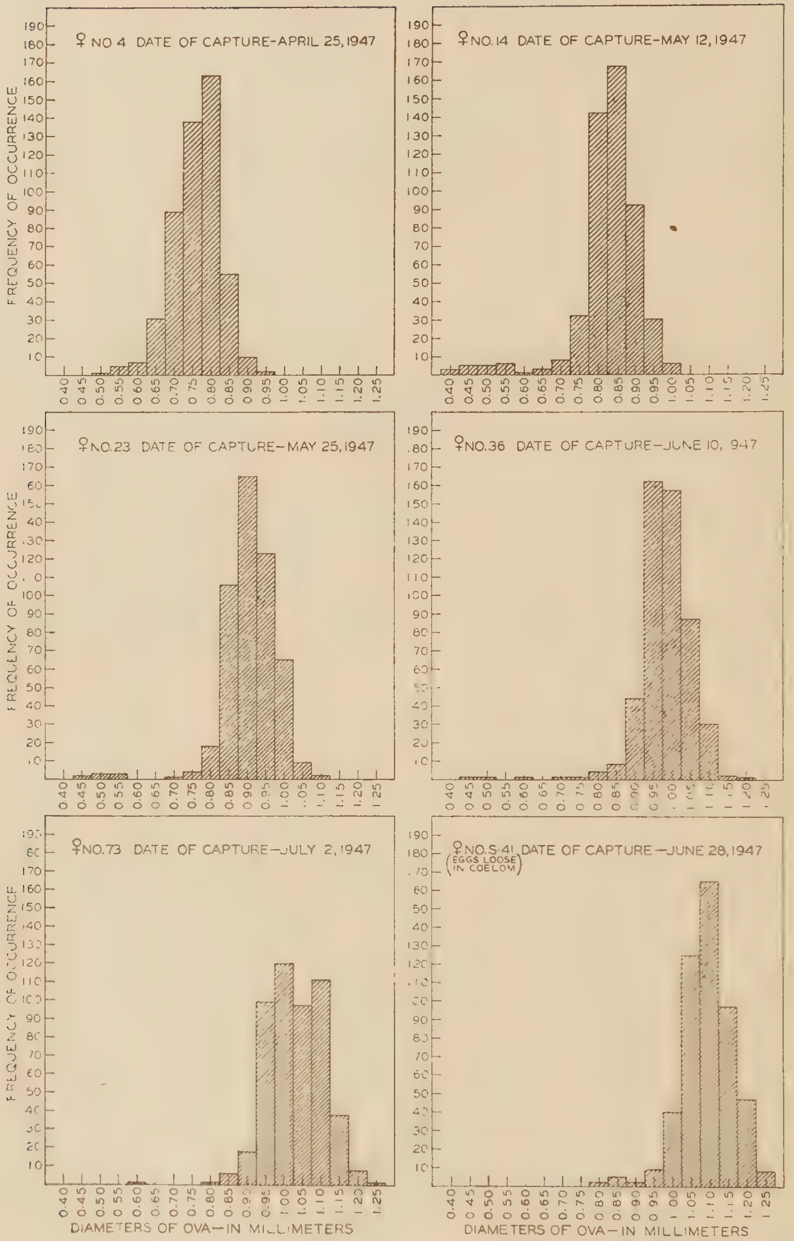

FIGURE 2

(For the explanation of the charts see the facing page.)

There was really very little difference in the accuracy of the two techniques (Table II). By the volumetric technique the calculated totals differed from the actual totals (numerical counts) by amounts varying from 0.0 to 10.4 per cent. The mean percentage error was +3.2. By the gravimetric technique deviations from actual totals varied from 0.0 to 9.7 per cent, with a mean percentage error of +2.5. The mean percentage errors of the two techniques are based on an algebraic average of the individual percentage errors. Although in most cases this statistic might produce an inaccurate result, it is felt that in this instance its application is justified. A mean error based on the algebraic sum of deviations expressed in numbers of eggs allows individual specimens (such as a small one of low egg count) to influence the results unduly, that is, a female which contains only 25,000 eggs and for which there is a ±1,000 egg deviation between calculated and actual totals has a large percentage error. This latter statistic is a very real measure of the efficiency of the calculating technique in that particular case. However, an equal numerical deviation in a larger and more productive specimen results in a much lower percentage error. It therefore follows that, if errors expressed in numbers of eggs tend to remain more or less constant (as they may if there is some small bias in the technique), too many small test specimens or too many large test specimens in a series will undoubtedly render too high or too low a mean error.

The preponderance of positive errors in calculating total egg production suggests some small bias in the techniques or procedures used. It is felt that the mean percentage error, as computed, provides the best measure of any bias, if it exists, resulting from some defect in the procedure. The mean percentage errors in this study are so small, however, that they may very well fall within the limits of chance occurrence. Consequently, the application of any small correction factor to the calculated data on egg production is not suggested.

The gravimetric method was utilized in calculating total egg production for the remaining sixty specimens because, apparently, the smallest

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EXPLANATION OF FIGURE 2

FIG. 2. Frequency distributions of ovum diameter measurements from sea lampreys taken on successive dates. Specimen No. 4 (represented at upper left) was a very early spawning migrant; specimens numbered 14, 23, and 26 were captured prior to or during the peak of the run; specimen No. 73 was taken after the peak of the run. Specimen No. S–41 (represented at the lower right) was a female in which the fully ripe eggs had burst into the coelom

TABLE II

Egg Production of Ten Female Sea Lampreys as Determined by Numerical Counts Compared with Values as Determined Volumetrically and Gravimetrically from Sample Sections of the Ovaries

1. Specimen number	60	58	57	70	44	73	56	23	66	63
2. Place of capture	Ocqueoc River	Carp Creek	Carp Creek	Carp Creek	Carp Creek	Carp Creek	Carp Creek	Carp Creek	Cheboygan River	Ocqueoc River
3. Date	6/16/47	6/15/47	6/15/47	6/26/47	6/11/47	7/2/47	6/15/47	5/25/47	6/26/47	6/20/47
4. Total length in inches	12.6	14.2	14.9	15.0	16.3	17.0	17.1	17.5	18.0	21.1
5. Total length in millimeters	320	361	378	381	414	432	434	445	457	536
6. Weight in grams	70	100	137	128	182	178	165	168	236	316
7. Total eggs by numerical count	23,986	21,000	48,694	66,537	53,012	67,604	59,185	55,486	69,736	107,138
8. Total eggs in sample section, by actual count	1,343	1,962	9,372	8,594	8,929	6,951	3,470	3,684	6,686	5,703
9. Total volume of ovary (cc.)	12.5	13.6	34.8	37.6	37.9	55.5	46.7	28.2	66.3	76.9
10. Volume of sample section (cc.)	0.7	1.3	6.6	4.4	6.0	5.2	2.7	2.0	6.0	3.9
11. Calculated number of eggs	23,982	20,526	49,416	73,440	56,402	74,189	60,018	51,944	73,880	112,451
12. Percentage error	0.0	− 2.3	+ 1.5	+ 10.4	+ 6.4	+ 9.7	+ 1.4	− 6.4	+ 5.9	+ 5.0
13. Total weight of ovary (grams)	13.50	13.93	32.49	34.86	36.30	51.55	45.97	28.81	65.18	73.44
14. Weight of sample section (grams)	0.68	1.30	5.70	4.56	5.93	5.15	2.72	1.97	6.11	3.86
15. Calculated number of eggs	26,662	21,024	53,420	65,699	54,658	69,577	58,646	53,876	71,325	108,505
16. Percentage error	+ 11.1	0.0	+ 9.7	− 1.3	+ 3.1	+ 2.9	− 0.9	− 2.9	+ 2.3	+ 1.3
17. Egg production of specimen*	24,021	21,000	48,694	66,552	53,026	67,617	59,198	55,491	69,806	107,138

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* Where these figures differ slightly from actual numerical counts listed in line 7, it is due to the addition of a small number of eggs not preserved, but counted, at the time of collection.

TABLE III

Data on Size, Weight, and Egg Production for Seventy Sea Lampreys, with Weights of Ovaries and Calculated Number of Eggs Produced

Specimen number	Total length (inches)	Total length (mm.)	Total weight (grams)	Weight of ovary (grams)	Calculated egg production	Correction*	Total egg production
60	12.6	320	70	13.50	...	..	24,021†
61	12.6	320	61	11.88	31,162	44	31,206
28	13.4	340	81	11.31	41,959	37	41,996
37	13.7	348	101	13.90	36,372	16	36,388
59	13.9	353	90	20.65	46,387	51	46,438
58	14.2	361	100	13.93	...	..	21,000†
21	14.4	366	104	6.62	42,103	19	42,122
16	14.6	371	129	14.67	37,735	40	37,775
53	14.6	371	100	21.85	50,449	22	50,471
31	14.6	371	137	19.56	55,898	56	55,954
54	14.7	373	92	16.32	37,445	24	37,469
49	14.7	373	99	22.98	41,910	6	41,916
57	14.9	378	137	32.49	...	..	48,694†
13	15.0	381	122	15.75	46,622	8	46,630
70	15.0	381	128	34.86	...	..	66,552†
7	15.1	384	135	12.97	38,335	0	38,335
3	15.3	389	110	10.37	45,776	0	45,776
55	15.5	394	110	20.20	38,294	8	38,302
51	15.5	394	136	38.97	46,266	15	46,281
38	15.5	394	179	31.85	74,917	55	74,972
46	15.9	404	132	26.46	48,875	5	48,880
47	16.0	406	150	31.38	44,203	2	44,205
34	16.1	409	137	18.90	46,417	10	46,427
48	16.2	411	160	38.66	57,954	9	57,963
44	16.3	414	182	36.30	...	..	53,026†
15	16.4	417	142	16.98	61,023	0	61,023
1	16.7	424	149	16.43	57,519	20	57,539
52	16.8	427	158	43.65	69,236	1	69,237
22	16.9	429	143	20.55	43,784	24	43,808
26	17.0	432	170	19.65	43,976	34	44,010
19	17.0	432	151	22.52	65,953	18	65,971
73	17.0	432	178	51.55	...	..	67,617†
56	17.1	434	165	45.97	...	..	59,198†
4	17.2	437	134	13.40	48,183	17	48,200
36	17.2	437	246	36.17	52,569	2	52,571
14	17.2	437	165	23.10	59,663	11	59,674
18	17.2	437	175	21.93	61,970	2	61,972
2	17.2	437	222	22.97	80,440	0	80,440
9	17.3	439	155	13.70	58,423	0	58,423
69	17.3	439	176	33.82	69,657	51	69,708
27	17.3	439	198	31.38	82,373	16	82,389
23	17.5	445	168	28.81	...	..	55,491†
12	17.8	452	182	14.55	55,801	12	55,813
66	18.0	457	236	65.18	...	..	69,806†
68	18.0	457	216	40.41	73,688	0	73,688
35	18.0	457	253	40.28	84,330	34	84,364
41	18.0	457	228	49.52	91,373	21	91,394
40	18.1	460	216	48.61	77,425	0	77,425
65	18.2	462	222	65.45	83,261	72	83,333
5	18.4	467	179	14.72	47,670	48	47,718
50	18.4	467	198	47.02	60,912	3	60,915
20	18.5	470	236	45.54	80,135	8	80,143
11	18.6	472	183	13.52	61,821	37	61,858
32	18.6	472	251	40.32	77,898	9	77,907
6	19.0	483	202	26.92	53,147	0	53,147
42	19.0	483	186	30.04	60,675	25	60,700
8	19.0	483	226	35.82	73,501	0	73,501
67	19.0	483	283	77.95	86,829	15	86,844
39	19.2	488	277	54.45	77,481	5	77,486
30	19.4	493	303	58.53	79,934	14	79,948
29	19.6	498	285	49.02	73,101	10	73,111
45	19.6	498	262	35.55	91,414	18	91,432
33	19.7	500	231	32.78	82,299	21	82,320
24	19.7	500	285	56.67	97,263	25	97,288
10	19.8	503	240	26.31	76,830	6	76,836
17	20.2	513	328	48.31	93,881	16	93,897
43	20.3	516	296	56.72	87,118	12	87,130
25	20.5	521	221	37.00	76,223	12	76,235
62	20.5	521	270	59.55	94,515	11	94,526
63	21.1	536	316	73.44	...	..	107,138†

Number of eggs not preserved at time of collection.
† Total number of eggs determined by numerical count (see Table I).

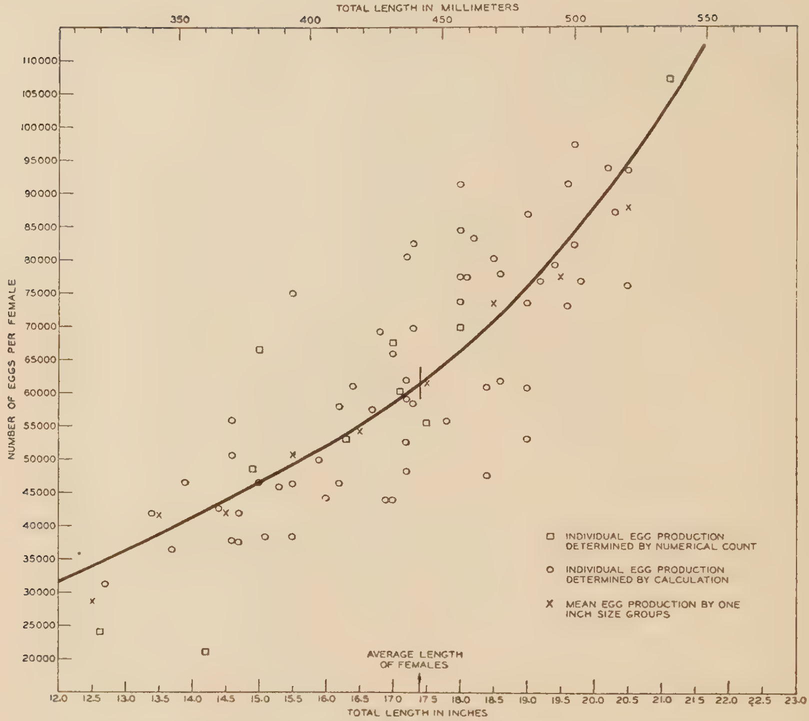

FIG. 3. Relationship between the number of eggs produced and the total length of the fish for seventy sea lampreys

TABLE IV

ESTIMATED MEAN EGG PRODUCTION BY ONE-INCH SIZE GROUPS AS DETERMINED FROM THE CURVE PROJECTED IN FIGURE 3, AND MEAN DEVIATION FOR EACH GROUP

Midpoint of size group (inches)	*Mean egg production*	*Mean deviation*
12.5	34,000	. . . *
13.5	38,700	4,449
14.5	43,800	7,805
15.5	48,300	8,960
16.5	55,200	7,287
17.5	62,200	8,541
18.5	70,600	10,560
19.5	81,900	9,896
20.5	94,800	6,853
21.5	110,300	. . . *

* Too few specimens to warrant computation.

error was involved in this technique and because the laboratory procedure is more rapid by this method. Data on size, weight, and egg production have been tabulated in order of increasing total length of specimens in Table III. If data are available for more than one specimen of a given length, these are listed in order of increasing egg production. These data have been plotted upon two graphs to illustrate the relationship between egg production and total length (Fig. 3) and between egg production and weight (Fig. 4).

The first property evident in these figures is that the number of eggs produced by the sea lamprey varies greatly at any particular length or weight. Mean egg production was computed by one-inch size groups and by 50-gram weight groups, and these values were plotted upon the respective graphs. The curves appearing in Figures 3 and 4 have been fitted by inspection to these mean values. The number of eggs produced increases quite rapidly with increase in total length; however, with increasing weight egg production is more directly proportional. The low-

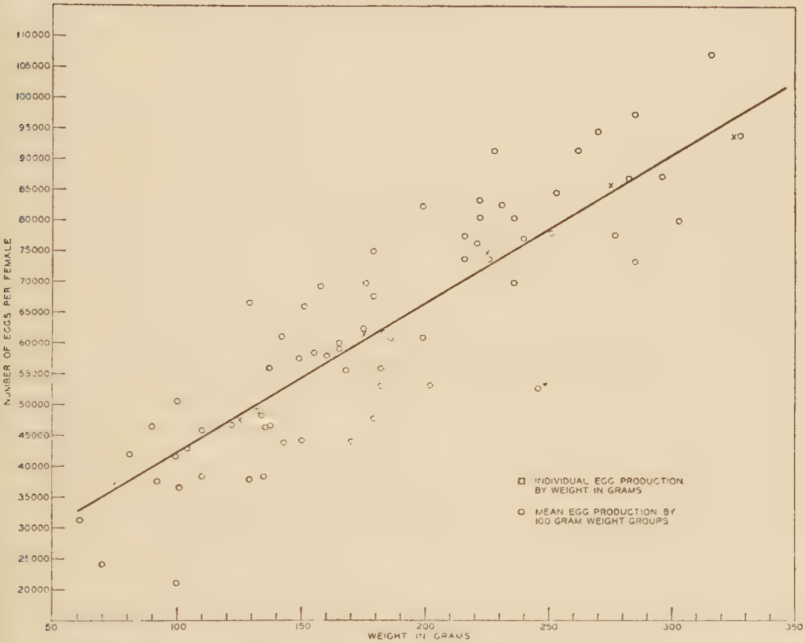

FIG. 4. Relationship between the number of eggs produced and the weight of the fish for seventy sea lampreys

TABLE V

NUMBER OF UNSPAWNED EGGS (DEVELOPED AND PARTIALLY DEVELOPED) IN FORTY SPENT AND DEAD OR DYING SEA LAMPREYS AND ESTIMATED PERCENTAGE OF POTENTIAL EGG PRODUCTION UNSPAWNED FOR EACH INDIVIDUAL

Specimen number	Date of collection (1947)	Total length (inches)	Total length (mm.)	Weight (grams)	Unspawned eggs		Potential egg production*	Estimated percentage unspawned
					Partially developed	Developed		
1	July 2	11.8	300	64	2,152	2,998	31,000	9.6
2	June 24	12.0	305	88	224	121	31,700	0.4
18	July 3	12.4	315	67	. . .	112	33,600	0.3
36	July 2	12.6	320	92	. . .	9,880	34,500	28.6
10	July 3	12.7	323	84	1,227	77	35,000	0.2
29	June 24	12.8	325	101	. . .	13,215	35,500	37.2
38	June 28	12.9	328	99	. . .	104	36,000	0.3
37	June 28	13.1	333	82	. . .	1,809	36,900	4.9
21	June 24	13.2	335	75	. . .	69	37,300	0.2
16	July 1	13.3	338	104	. . .	4,980	37,800	13.2
27	June 23	13.4	340	103	. . .	519	38,300	1.4
24	June 24	13.4	340	103	. . .	225	38,300	0.6
3	June 22	13.7	348	102	899	74	39,700	0.2
9	July 1	13.8	351	79	470	3,879	40,200	9.6
5	July 1	14.0	356	99	227	251	41,300	0.6
32	July 2	14.3	363	102	. . .	647	42,800	1.5
8	July 2	14.4	366	99	55	5	43,300	0.0
7	June 24	14.4	366	78	134	1,518	43,300	3.5
15	July 7	15.5	368	108	. . .	453	43,800	1.0
23	June 28	14.6	371	156	. . .	124	44,400	0.3

* Based on values obtained from curve projected in Figure 3.

Specimen number	Date of collection (1947)	Total length (inches)	Total length (mm.)	Weight (grams)	Unspawned eggs		Potential egg production*	Estimated percentage unspawned
					Partially developed	Developed		
34	June 29	14.7	373	131	. . .	6,392	45,000	14.2
33	June 24	14.7	373	118	. . .	6,386	45,000	14.2
22	June 29	14.8	376	119	. . .	222	45,500	0.5
19	July 2	14.9	378	104	. . .	148	46,000	0.3
13	June 23	15.0	381	117	. . .	470	46,500	1.0
4	July 3	15.0	381	144	. . .	366	46,500	0.8
20	June 30	15.0	381	145	. . .	271	46,500	0.6
40	June 29	15.1	384	161	. . .	820	47,100	1.7
17	July 2	15.6	396	166	. . .	322	49,800	0.6
39	June 28	15.6	396	126	. . .	354	49,800	0.7
6	July 2	15.7	399	112	33	48	50,400	0.0
31	June 29	15.9	404	166	. . .	790	51,600	1.5
26	July 1	15.9	404	153	. . .	92	51,600	0.1
28	July 3	16.3	414	186	. . .	2,113	54,000	3.9
25	June 28	16.4	417	203	. . .	10,584	54,500	19.4
12	June 26	16.7	424	116	. . .	980	56,500	1.7
14	July 2	16.8	427	123	. . .	1,397	57,100	2.4
35	June 28	16.8	427	201	. . .	11,101	57,100	19.4
30	July 2	17.0	432	192	. . .	1,806	58,400	3.1
11	June 20	18.1	460	236	47	205	67,000	0.3

* Based on values obtained from curve projected in Figure 3.

est egg production recorded, 24,021 eggs, was found in a 12.6-inch (320 mm.) female weighing 70 grams. The greatest recorded, 107,138 eggs, was found in a 21.1-inch (536 mm.) female weighing 316 grams. Using values obtained from the curve projected in Figure 3, we find that the mean egg production of females of average length (17.4 inches, 442 mm.) is 61,500 eggs. Mean egg production for successive one-inch size groups, estimated from the curve in Figure 3, is given in Table IV, together with the mean deviation for each of the groups.

PERCENTAGE OF UNSPAWNED EGGS

The egg production determined for the sea lamprey in the preceding section represents the basic reproductive potential of the species in the region studied. This potential is obviously never realized in nature. Many factors inherent in the organism itself and in its environment tend to nullify the potential, and the actual productivity of the species may be very low when these factors are considered. A preliminary experiment in the number of ammocoetes (larvae) produced per spawning female suggests that the larval hatch per number of eggs produced (and spawned) is quite small.

One of the inherent factors which may contribute to a low productivity is the percentage of ripe eggs remaining in the female after the spawning act is completed, that is, the number of unspawned eggs. Forty spent females were collected to determine this percentage. In order to avoid any doubt whether they had completed as much of their spawning act as they were destined to, only dead (30) or obviously dying (10) specimens were collected. Most collections were made in the deeper pools below spawning riffles or in sloughs into which the dying lampreys had drifted. The females obtained ranged from 11.8 inches (300 mm.) to 18.1 inches (460 mm.) in total length.

For ten specimens separate counts were made of the partially developed and fully developed eggs. For the remainder only the fully developed eggs were counted. These data are presented in Table V, with appropriate data on collection, size, and weight. The partially developed eggs were, as a rule, still trapped in the remnants of the ovary. Some fully developed eggs were found in like position, but when larger numbers of these were present, by far the bulk of them were loose in the coelom. The potential egg production of each female was determined from the curve projected in Figure 3. By means of this figure and the number of developed eggs retained in females the estimated percentage of unspawned eggs was computed (Table V). The partially developed eggs were not considered in estimating this percentage since their occurrence is variable with length. They are present in nominal numbers only in all but the very smallest size groups.

As a general rule, only a very small percentage of developed (mature) eggs remain unspawned; the estimated average percentage was 5.0 per cent. Among the specimens there are, however, several notable exceptions. For two individuals the estimated percentages of unspawned eggs were 28.6 and 37.2. Two others were identical in having an estimated 19.4 per cent of their eggs unspawned. All the females displaying a relatively high percentage of unspawned eggs were late migrants, appearing at the very end of the spawning season. Observations made upon late migrants of both sexes indicate a very low vitality at that time. I suspect that these specimens examined which contained a large number of unspawned eggs were unable to complete their spawning act before approaching death made them incapable of doing so. In view of this, the average percentage of 5.0 unspawned eggs is believed to represent the maximum average that occurs; indications are that this average would be lower if computed for specimens found spent nearer the beginning of the spawning season.

ACKNOWLEDGMENTS

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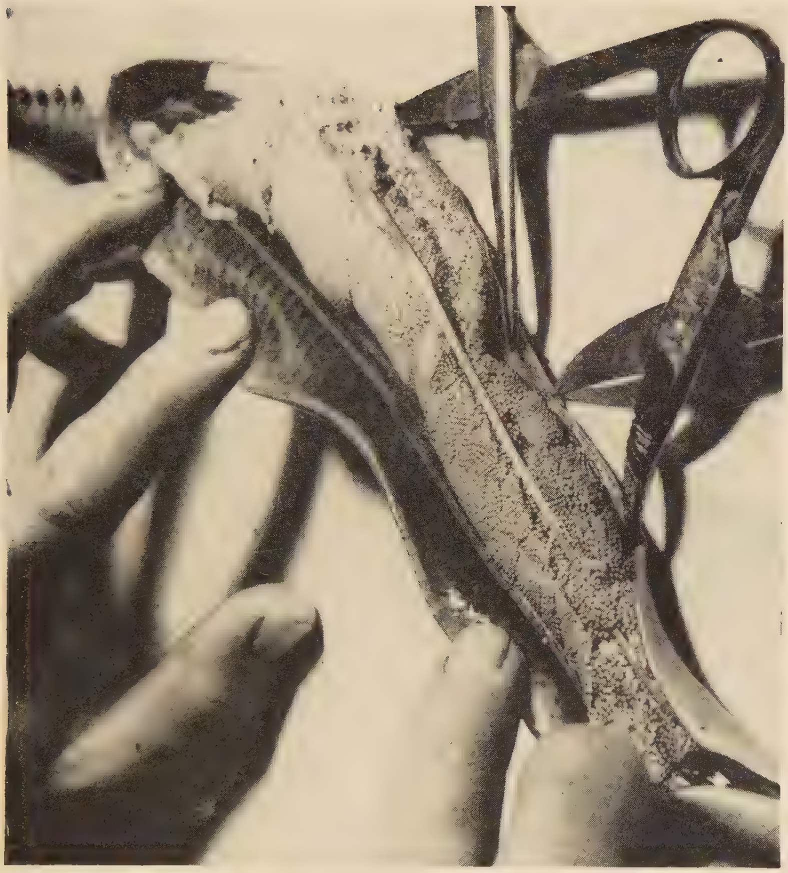

Dissection of a ripe female sea lamprey showing size, extent, and position of the ovary. Note the atrophied remains of the digestive tract lying on and within the ovary

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MOVEMENT AND DISPERSION OF A BLOCKED SPAWNING RUN OF SEA LAMPREYS IN THE GREAT LAKES

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As the result of a special Congressional appropriation (Public Law 249—81st Congress) the U. S. Fish and Wildlife Service's sea lamprey investigations were greatly expanded at the beginning of the 1950 calendar year. A number of investigations of both the biology of the sea lamprey and of methods of controlling that parasite are currently underway. This report is concerned with one of the studies completed during that year.

In several large Great Lakes watersheds sea lamprey spawning runs are blocked near the mouth of the main stream by power dams. An example of such a watershed is that of the Cheboygan River flowing into the northwest tip of Lake Huron at Cheboygan, Michigan. To determine whether or not it is worthwhile to trap and destroy these large runs which are prevented by barriers from reaching suitable spawning grounds, a tagging experiment was conducted in that river during the spring spawning migration of 1950. Conditions were favorable for such an experiment since relatively extensive facilities for the recapture of marked lampreys were present in the area. The Cheboygan River occupies an almost central location in an experimental sea lamprey control zone embracing an 80-mile reach of the northernmost Lake Huron shoreline of the Southern Peninsula of Michigan. Twelve weirs and traps for the capture and destruction of sea lamprey spawning runs were operated during the spring in all spawning streams in this zone. The zone is known as, and referred to hereafter, as Control Zone H-1. Other more distant weirs and traps, operated primarily by cooperating state agencies, in which tagged lampreys might possibly have been recovered were located as follows: Trail Creek, La Porte County, Indiana (tributary to southeastern Lake Michigan); Hibbard's and Lily Bay Creeks, Door County, Three Mile Creek and the Kewaunee River, Kewaunee County, East Twin River and Fisher Creek, Manitowoc County, Wisconsin (all tributary to central Lake Michigan); Black River, Mackinaw County, Michigan (tributary to northern Lake Michigan from the Upper Peninsula of Michigan); and Pendill's Creek, Chippewa County, Michigan (tributary to eastern Lake Superior). Several trapping devices were also operated by the Province of Ontario in streams tributary to the North Channel of Lake Huron directly across the lake from the site of the experiment.

Field experiments, anatomical studies, and other observations seemed to indicate that many of these blocked individuals do not locate suitable streams in which to spawn and ultimately die in the lake proper without spawning. The tagging experiment was conducted to find the answers to the following questions:

1. What proportion of a blocked run is diverted to other streams along the shoreline and what proportion disappears back into the lakes, presumably to die without spawning?

2. In what directions do blocked migrants travel, how far and how fast do they travel, and in what numbers do they enter other watersheds in relation to distance from the blocked stream?

3. Do these diverted migrants make a significant contribution to the spawning runs in other streams?

A total of 2,843 adult lampreys were trapped below the paper mill power dam in the Cheboygan River and tagged during the period May 7 to June 10, 1950. Of this number, 289 or 10.2 per cent were recovered. Of the lampreys recaptured, 254 were trapped in the sea lamprey weirs in the streams of Control Zone H-1, 34 specimens were returned through the cooperation of commercial fishermen who captured them in trap nets and gill nets set for other fishes, and the remainder was captured in a stream on the eastern tip of the Upper Peninsula (Figures 1 and 2; Table 1).

Forty-two lampreys taken had obviously been tagged but the tag had been torn out. A ragged, ''V-shaped'' scar was observed in the area where the tag had been placed. These lampreys were counted as tag recoveries in analyzing the data, except in those calculations involving the number of days between tagging and recapture. A few dead, marked lampreys were recovered from the Cheboygan River, most of them hanging by the tag from steel wire tangles (city refuse) on the river bottom. These were not counted in the total number tagged or as recoveries. From observations at time of tagging it is

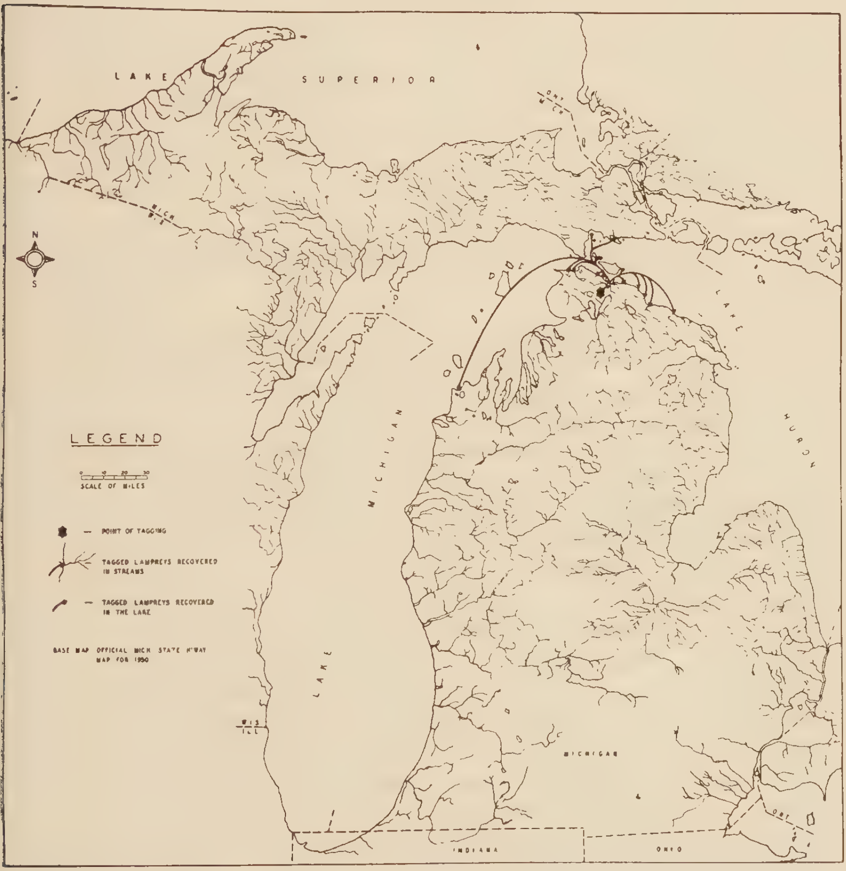
LAKE
SUPERIOR
N
S
LEGEND
0 10 20 30
SCALE OF MILES
POINT OF TAGGING
TAGGED LAMPREYS RECOVERED IN STREAMS
TAGGED LAMPREYS RECOVERED IN THE LAKE
BASE MAP OFFICIAL MICH STATE H'WAY MAP FOR 1950
LAKE MICHIGAN
LAKE HURON
MICHIGAN
INDIANA
OHIO
WIS
ILL

Figure 1. Small-scale chart of the upper Great Lakes showing general dispersion of marked lampreys from a blockaded spawning run.

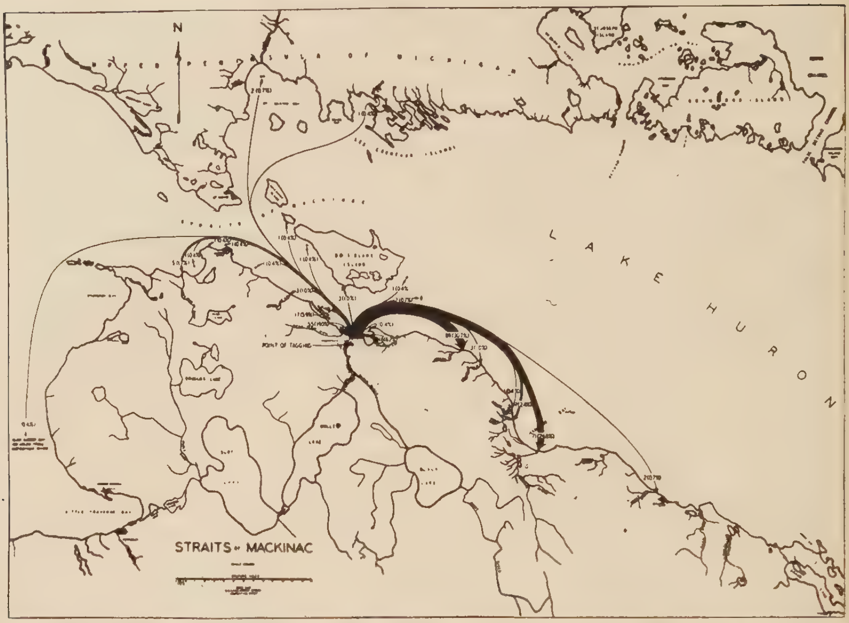

Figure 2. Large-scale chart of Control Zone H-1 (northern Lake Huron) showing movements of marked lampreys from the blockaded Cheboygan River spawning run.

known that few tagged lampreys escaped upstream through the power dam boat locks into the Mullett Lake—Burt Lake drainage.

Specimens for tagging were obtained by dipnetting at night below the paper mill power dam on the Cheboygan River. Sea lampreys collected early in one night were held in live boxes overnight and tagged the following morning. Originally a special experimental trapnet was operated but it proved to be inefficient because of improper mesh-size, strong currents, and the accumulation of large amounts of detritus on the webbing.

Two types of tags were used in the experiment. The first groups of the lampreys (1,585 individuals) were tagged with numbered Peterson-type tags, three eighths of an inch in diameter. One disc was red and the other was white. These were applied with 1¾-inch nickel wire pins through the dorsal musculature just anterior to the first dorsal fin. The remainder of the lampreys (1,258 individuals) were marked with numbered jaw tags of fingerling size. The jaw tags were clamped through the anterior portion of the first dorsal fin just above its juncture with the back. Prior to tagging, the lampreys were anesthetized with a 5 per cent solution of urethane. Anesthesized lampreys were measured, tagged, and held in a live box until they had

TABLE 1. LOCATION OF POINT OF RECOVERY OF MARKED SEA LAMPREYS AND DISTANCE FROM POINT OF TAGGING

(With number recovered, percentage of total tags recovered, percentage of total tagged, and days out)

Location	Distance from point of tagging in miles	Tags recovered		Percentage of total tagged	Days out		
		Number	Percentage		Minimum	Mean	Maximum
Control Zone H-1							
In streams							
Little Black River	2	55	19.0	1.93	2	10.7	30
Elliott Creek	3	18	6.2	0.63	2	10.3	26
Martin Creek	8	3	1.0	0.11	28	29.7	31
Green Creek	12	89	30.7	3.13	3	14.2	65
Milligan Creek	15	3	1.0	0.11	6	7.7	11
Grace Harbor Creek	23	1	0.4	0.04	11	11.0	11
Carp Creek	25	7	2.4	0.25	6	9.2	12
Carp Lake River	25	5	1.7	0.18	8	14.0	18
Ocqueoc River	30	71	24.5	2.50	4	14.8	37
Trout River	43	2	0.7	0.07	13	15.5	18
Total in streams	....	254	87.6	8.95	....	......	....
In the lake							
West of Cheboygan	2-5	17	5.9	0.60	2	15.5	42
Lighthouse Point	3	1	0.4	0.04	15	15.0	15
Poes Reef	5	2	0.7	0.07	27	38.5	50
Bois Blanc Island	5-10	5	1.7	0.18	11	25.4	35
Fly Point	15	1	0.4	0.04	14	14.0	14
Mackinaw City	17	2	0.7	0.07	6	10.7	14
Round Island	17	1	0.4	0.04	31	31.0	31
Cecil Bay	23	1	0.4	0.04	12	12.0	12
Total in lake	....	30	10.6	1.08	....	......	....
Total in Control Zone H-1	....	284	98.2	10.03	....	......	....
Other areas							
In streams							
Mackinaw Creek (Hessel, Mich.)	25	1	0.4	0.04	(6 to 19 days)		
In the lake							
St. Martins Bay (Lake Huron)	25	3	1.0	0.11	7	12.0	21
Glen Arbor Bay (Lake Michigan)	150	1	0.4	0.04	....	52	....
Total in other areas	....	5	1.8	0.19	....	......	....
Grand Total	....	289	100.0	10.22	2	......	65

recovered fully. They were then released. No lampreys so handled were held in excess of 2 hours. Any individuals not appearing fully recovered in this time were destroyed to exclude them from the experiment.

There was evidently a difference in the efficiency of the two types of tags used. Of the 247 tags recovered, only 74 were jaw-type tags. It was noted that lampreys taken in commercial gear were almost always captured when the Peterson-type tag became entangled in the mesh. The jaw tag could not similarly ensnare the lamprey. If the 34 Peterson-type tags recovered in the commercial fishery are disregarded, the jaw tags still made up only 35 per cent of the tags recovered although 44 per cent of the lampreys were marked with this type of tag. The difference in efficiency still evident in the figures after this adjustment is probably attributable to difficulty in detecting the small tags under night working conditions at the weirs. The large red and white disc tags were highly visible even in subdued light.

The recovery of 254 marked lampreys in the weirs and traps of Control Zone H-1 indicates that at least 9 per cent of the blocked Cheboygan River run was diverted to other streams within the zone in both directions along the shoreline. The Cheboygan River sea lamprey run was conservatively estimated by experienced observers at 40,000 migrant individuals. On the basis of this estimate, the total number tagged, and the percentage recovery of tags, it appears that about 3,600 of the spawning run sea lampreys captured in the streams of the control zone were diverted Cheboygan River migrants. By the same token, 91 per cent or an estimated 36,400 sea lampreys from the blocked run were diverted into streams outside the control area or wandered aimlessly in the lakes, presumably to die without spawning.

Several tagged lampreys were taken by commercial fishermen in the Straits of Mackinaw, St. Martins Bay, and Mackinaw Creek near Hessel, Michigan. These recoveries indicate that many of the Cheboygan River migrants find their way across the deeper waters of the Straits and into the streams and rivers of the Upper Peninsula of Michigan and perhaps contribute significantly to the spawning runs of those streams.

The portion of the blocked run that is diverted into other streams apparently moves in all directions from the mouth of the Cheboygan River with the majority following the Lake Huron and Lake Michigan shorelines of the Lower Peninsula (Figures 1 and 2). It is difficult to define the farthest limits of dispersion of the blockaded Cheboygan River run as there were few devices for recapturing the tagged specimens in any area other than Control Zone H-1. Since little publicity concerning the experiment was given beyond the local area, it is entirely possible that some tags recovered by commercial fishermen in more distant locales were not returned. It is significant, however, that no tagged lampreys were taken in the Pendill's Creek weir and trap (Chippewa County, Michigan), the Black River weir and trap (Mackinaw County, Michigan), the Trail Creek trap (La Porte County, Indiana), and of the six installations operated in Wisconsin, or those operated by the Province of Ontario.

The most distant reported recovery was from Glen Arbor Bay, Lake Michigan, approximately 150 miles west and south of Cheboygan (Figure 1). This lamprey was taken by a commercial fisherman in a gill net 52 days after it was tagged and released at the power dam. In the other direction the farthest recoveries were two lampreys taken in the trap in Trout River, Presque Isle County, Michigan, 43 miles east of the point of tagging (Figure 2). The first capture was recorded 13 days after release and the second 5 days later.

Evidently little correlation exists between distance traveled and the number of days elapsing between tagging and recapture within the limited area where devices were present for recovering the migrants. The number of days from the time the lampreys were tagged until they were recovered varied greatly (Table 1). Within a radius of 2 to 10 miles of the point of tagging, total time out varied from 2 to 50 days; 11 to 20 miles distant it varied from 3 to 65 days; and 21 to 43 miles away it varied from 4 to 37 days. Obviously some of the tagged lampreys wandered in the Lakes for a considerable time before entering another stream in search of a spawning area. Others apparently did not deviate from the most direct route to the stream they entered.

The influence of the diverted Cheboygan River run on the runs of other streams varied with the size of the stream and the distance from the Cheboygan River. For example, the Ocqueoc River, which is the largest unobstructed stream in Control Zone H-1, is 30 miles east and south of the point of tagging; 71 tagged lampreys were trapped there. Green Creek, 12 miles east of Cheboygan is only about one tenth the size of the Ocqueoc River and yet 89 tagged lampreys were captured in this stream. In two even smaller streams, Elliott Creek (3 miles distant) and Little Black River (2 miles distant) 18 and 55 tagged specimens, respectively, were recovered (Table 1).

Significant contributions by the blocked Cheboygan River run were made to other runs in streams 40 miles distant alongshore in one direction and 25 miles in the other. The proportion of lampreys among the runs of the several streams studied that had their origin in the Cheboygan River varied inversely with distance from that blockaded stream (Table 2). For instance, the Little Black River, 2 miles west of Cheboygan, had a run of 953 lampreys. On the basis of the

TABLE 2. PROBABLE CONTRIBUTION OF THE BLOCKED AND DIVERTED CHEBOYGAN RIVER SEA LAMPREY RUN TO THE RUNS IN OTHER NEARBY STREAMS WITH ACCESSIBLE SPAWNING GROUNDS

Location of stream	Distance in miles from the Cheboygan River	Total number of lampreys entering stream[1]	Probable proportion of run that were diverted migrants from Cheboygan River: Number	Percentage
Little Black River	2	953	772	81.0
Elliott's Creek	3	266	253	95.0
Green Creek	12	1,945	1,252	64.0
Milligan Creek	15	700	42	6.0
Carp Creek	25	1,161	98	8.4
Carp Lake River	25	3,821	76	2.0
Ocqueoc River	30	18,882	1,000	5.3
Trout River	43	1,702	28	1.6

[1] Number taken in weir and trap.

aforementioned estimate of 40,000 lampreys as the size of the blocked Cheboygan River run, the 55 tagged lampreys recovered in this stream would indicate that 772 specimens or 81 per cent of the total catch were diverted lampreys. From similar computations it is found that in the Carp Lake River, 25 miles west of Cheboygan, 2 per cent or 76 of the 3,821 individuals taken there were from the Cheboygan River run. In an easterly direction, 95 per cent or an estimated 253 of the lampreys taken in Elliott Creek (3 miles distant) were diverted migrants. It is further indicated that of the run in Green Creek, 12 miles east, 64 per cent were originally from the same river. The Ocqueoc River, 30 miles east, attracted an estimated 1,000 individuals from the diverted run. This figure was only 5.3 per cent of the total Ocqueoc River run. The two tagged lampreys caught in the Trout River weir and trap, 43 miles distant, indicated that 1.6 per cent or a probable 28 individuals of this run had originally entered the Cheboygan River.

It is apparent from the results of this tagging experiment that a significant portion of such a blocked run is diverted to other streams in the immediate area which have accessible spawning grounds. Significant contributions by this blocked run were made to spawning runs in streams 40 miles distant alongshore in one direction and 25 miles distant in the other. It was also of interest to note that some sea lampreys swam offshore, rather than following the shoreline in their search for a spawning stream, crossed the Straits of Mackinaw, and appeared off the shoreline and in streams of the Upper Peninsula of Michigan.

It may be concluded from this experiment that trapping operations to ''siphon off'' these large blocked runs may be of considerable beneficial effect. Against such action is the observation in Control Zone H-1 that these blocked and diverted migrants appearing in other streams contributed only a portion to an already existing surplus of lampreys entering these streams for which no spawning facilities were available.

DISCUSSION

DISCUSSION LEADER OLDS: Thank you very much. Probably the study of the sea lamprey in the Great Lakes has recently excited as much interest among fishery men on this Continent as any other single problem, and this report, I am sure, has been awaited rather eagerly and anxiously as is indicated by the full attendance in this afternoon's session. I am sure that there will be some questions or comments which a number of those present will wish to make. Do you have questions or comments at the present time?

MR. RALPH S. NANZ (Wisconsin): I would like to know what consideration you have given to the idea that the St. Lawrence Waterway will undo all the good that this experimental work on the lampreys may do. Will that ruin the whole thing?

MR. BERNARD R. SMITH: I am not directly concerned with this, but I may be able to answer that question. We don't hope to exterminate the lamprey, but we do have hopes for its control, and the time it takes to reinfest the Lakes through the St. Lawrence Waterway, and also through the Welland Canal, probably will only be a small contribution to what is already here anyway, even if we do find a control.

MR. JOHN E. BARDACH (Iowa): You said that some of the lamprey were deviated for 3 or 4 weeks. How effective was their spawning after they found new spawning streams?

MR. BERNARD R. SMITH: Apparently the lamprey can spawn just as effectively even after having held their spawn for a considerable length of time. At the lab we have held specimens taken from the weirs for 2 months aftr the normal spawning time, and have, through artificial means, hatched young lampreys, so apparently they hold them.

MR. J. R. SMITH (Wisconsin): Naturally our fishermen have been affected by the lamprey's activity. What can we expect in the way of effective control during this coming season?

MR. BERNARD R. SMITH: I am afraid that there is no practical control for this coming season. As you know, the control measures which we are using are only experimental in nature now, and even if we did have a hard and fast control the effects wouldn't be felt for several years anyway.

Reprinted from Copeia, 1951, No. 1, March 21

NORTHWARD DISPERSAL OF WARM-WATER MARINE FISHES IN SOUTHERN NEW ENGLAND DURING THE SUMMER OF 1949.—Record high temperatures that prevailed throughout the eastern seaboard states in 1949, especially in the summer months, were probably a major factor in the appearance in the coastal waters of Rhode Island and southern Massachusetts of numerous forms of marine life that typically occur in semi-tropical or tropical environments. The following list of fishes in this category has been compiled from data furnished by Mrs. Charles J. Fish of the Narragansett Marine Laboratory, Rhode Island, from specimens brought to the Fish and Wildlife Service laboratory at Woods Hole, Massachusetts, by commercial and sports fishermen of the Cape Cod area, and by personal observations.

Gymnura altavela (Linnaeus), butterfly ray.—Very rare on the Atlantic Coast, a single specimen once having been recorded from Woods Hole, Massachusetts. A member of this warm-water species measuring 4 feet across the wings was taken at Point Judith, Rhode Island, in August.

Synodus foetens (Linnaeus), lizard fish.—Rare north of the Carolinas, this species was relatively abundant during mid-summer along the coast and in various bays and coves of southern New England. Three specimens brought to the Woods Hole laboratory for identification were 15.2 cms., 17.8 cms., and 22.5 cms. in total length. They were taken by sport fishermen who related that each fish struck savagely but fought with short-lived energy. One was caught on a piece of squid during surf-fishing operations off Craigville Beach, Hyannis, Massachusetts; one was caught on a Japanese feather lure at Osterville, Massachusetts; and the other (one of 4 caught) hit a trolled fluted spoon off Monument Beach, Buzzards Bay, Massachusetts. In Wickford Harbor, Rhode Island, one lizard fish leaped into a skiff while in frenzied pursuit of silversides. Large numbers of this species were observed here, voraciously feeding on silversides and small menhaden. The lizard fish, which has the same general shape and feeding habits as the barracuda, is no doubt often mistaken for that predator. Several rumors that barracuda had been caught by anglers throughout this area were definitely traced to *S. foetens*.

Coryphaena hippurus (Linnaeus), dolphin.—Heretofore appearing off the southern New England coast as an occasional tropical straggler, many dolphin were observed during mid-summer in Block Island Sound off Point Judith, Rhode Island, and in the vicinity of No Man's Land off the coast of Massachusetts, where numbers were taken by sport fishermen on various lures. In addition, 6 immature dolphin, averaging 40 cms. fork length, were taken in mid-August from a fish trap a quarter of a mile offshore in lower Buzzards Bay, Massachusetts. These colorful fish were kept alive for several days in our Woods Hole laboratory and were a source of considerable interest.

Peprilus alepidotus (Linnaeus), harvest fish.—Uncommon north of New Jersey, a 23.5-cm. (fork length) specimen was caught off Race Point, Massachusetts (off the tip of Cape Cod just north of Provincetown), in October by a commercial dragger. Other summer records from the Gulf of Maine are cited by Bigelow and Schroeder (1936, Bull. U. S. Bur. Fish., 48: 333).

Auxis thazard (Lacépède), frigate mackerel.—Erratic in its migrations, known from all warm seas, and only rarely reaching our coast line, the frigate mackerel was present in great numbers in the vicinity of Point Judith during mid-August. According to reliable observers, these fish "fairly swarmed" in huge schools. Many were caught by commercial fishermen (largely in traps), and, although usually considered to be an inferior food fish, they sold well.

Scomberomorous maculatus (Mitchill), spanish mackerel.—Not common in Cape Cod waters even in summer, a 61.0-cm. specimen (fork length) was taken on October 16, 1949, in North Bay, Cotuit, Massachusetts.—EDGAR L. ARNOLD, JR., *U.S. Fish and Wildlife Service, Woods Hole, Massachusetts.*

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FEEDING HABITS OF ADULT SHAD (*ALOSA SAPIDISSIMA*) IN FRESH WATER[1]

The American shad (*Alosa sapidissima*) is an anadromous fish that upon maturity enters streams along the Atlantic and Pacific coasts each spring and early summer to spawn. It has been the common belief of previous workers that the shad do not feed to any extent while in fresh water, accounting for the progressive decrease in fat content during their fresh water stay, the formation of spawning marks on the scales, and if their stay is prolonged, a possible cause of mortality. Leim (1924) summing up the opinions of early writers, as well as his own observations, states that "shad did not feed actively (in fresh water), but only took such things as came their way." Leach (1925) says that "after entering the rivers the shad takes but little, if any, food previous to spawning but after casting its eggs, it bites at flies or any small shining object, and has been known to take the artificial fly." Moss (1946) notes that "It is believed that adult shad eat but very little or not at all while in fresh water." Consequently, I was rather surprised when adult, unspawned shad recently placed in a fresh water pond at the U. S. Fishery Laboratory, Beaufort, North Carolina (Sykes 1951) began actively to take a diet of ground fish as well as a liver - fish meal mix.

A total of seventeen adult shad (ten males, seven females) were placed in a fresh water pond about sixty feet square and with the water averaging two feet in depth. A small flow of fresh water from an artesian well nearby replenishes water lost from seepage and evaporation. On May 19, the water temperature was 24.5° C.

A small amount of food had been thrown into this pond since the introduction of the shad, April 17 to 25. On May 9, the shad were seen to congregate in the area where food was placed, apparently feeding.

Further observations on May 12 and 19 showed that: (1) within three minutes after food was tossed into the pond, all seventeen shad were in the feeding area eagerly swimming through the settling food; (2) bits of food seen to be taken by individual shad with no dence of subsequent rejection; and (3) afte remaining food had settled to the bottom, shad were seen to swim back and forth clo the bottom, stirring up mud and food ali order to get the food before it had resettle most curious behavior.

On occasion, these shad have been obse to "fin" in order to take terrestrial insects have accidentally fallen into the water, but have not yet been observed to jump for flying insects as have the year-old juvenile in a neighboring pond. This chance captu terrestrial insects would be too rare to fo substantial part of the diet of shad.

Although frequently behavior of fish unde perimental conditions is quite different from found in nature, there is some evidence that feed while in the rivers to spawn. For exa anglers do take considerable numbers of spawned shad in the Connecticut River, i Susquehanna, and in other Atlantic streams. Certainly shad must have more a passive interest in food to take the arti lures offered by fishermen. The fact that will choose individual organisms agrees s what with observations of the feeding habi the closely-related alewives (Bigelow 1926)

Then there is the work on the related Cas shad (*Caspialosa caspia*), Chajanova (19 showing that shad feed equally intensively ing the pre-spawning, spawning, and spawning periods, yet Zamakhaev (1940) f a rapid loss of hypodermic fat during spaw similar to that generally reported in our and in other anadromous fishes.

These observations do not explain the abs of food in the stomachs as reported in prev studies. We know that shad are "plan feeders," characteristically swimming with gill covers extended straining the water for Among the clupeids, Bigelow (1926, p. notes the direct relationship between the fine of the sieve formed by the gill rakers and minimum size of the organisms that can be tained and utilized. In the sea the adult (i.e. over 40 cm.) feed to a large exten mysids (Leim 1924) 10 to 30 mm. in length fresh water the largest plankton found in a dance are copepods which rarely exceed 5

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[1] The shad investigation of the Fish and Wildlife Service, of which this experiment is a part, is being carried on to furnish information for fishery regulations to the Atlantic States Marine Fisheries Commission.

th. It seems most likely, then, that the
for the absence of food in the stomachs
in fresh water is that the available food
mall to be collected; we are certain that
had are both interested in food and cap-
feeding during their stay in fresh water
roper sized food were present.

SUMMARY

rary to previous reports of shad not feed-
ile in fresh water, mature shad placed in
-water pond at the Fishery Laboratory,
rt, N. C., actively fed on ground fish and
er - fish meal mix. The shad, which are
y plankton feeders, took the food either
ttled through the water or by swimming
nd forth close to the bottom, stirring up
nd food alike and straining out the food
it had resettled. Absence of food in
hs of shad taken from fresh-water
s is probably attributable to the size of
sh-water forms, since the available plank-
probably too small to be retained by the
ers and utilized for food.

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Growth Characteristics of the Poeciliid Fish *Platypoecilus maculatus*[1]

By Frances E. Felin

ONE of the primary problems in fishery biology is that of distinguishing discrete populations of food fishes. This is frequently done by morphometric studies of local forms, and Ehrenbaum (1929) has pointed out that such studies have "not merely a theoretical but also . . . practical importance in the interests of rational utilization of the stock."

It has been suggested by Lea (1929) that growth characters might serve as accessory race characters. He and his associates have shown that the scale patterns in Norwegian herring, *Clupea harengus* Linnaeus, reflect differences in growth types, and also reveal place of origin and the stock to which an individual or a population belongs.

Ford (1933) experimented with regression equations of the type $y = a + bx$ as a technique for the comparison of growth in length in different geographical areas. Other biologists, for example Bückmann (1938) also have discussed the application of this equation to growth phenomena. This technique is based on the correlation between calculated length of herring at the formation of a given winter ring (l_n) and the calculated length at the time the next ring is laid down (l_{n+1}). Thus $l_{n+1} = a + bl_n$. The formula also indicates that growth follows a geometric progression with annual increments becoming smaller and smaller in constant ratio. Differences due to annual changes in conditions of growth are recognized, however, and the geometric law is regarded as the smoothing out of real fluctuations which are likely to recur year after year.

Differences in growth between herrings of different geographical areas were expressed by Ford in a series of regression equations and calculated "limiting values," or asymptotic limits of growth, which changed from south to north. These growth equations were derived from data on mean calculated lengths of herring from l_1 to as old as l_{13} caught in the North Sea, the English Channel and off Iceland. The values for the slope of the regression lines varied from around 0.6 in Lowestoft herring to 0.74 for the Icelandic forms, with predicted ultimate size (y-intercept ÷ complement of slope) similarly differing from 27.5 cms. in the south to 36.2 cms in the north.

Walford (1946) described a convenient graphic method for plotting that part of the growth that lies beyond the inflection point of the ordinary sigmoid curve that is derived by plotting length against age. He "transformed" this portion of the usual curve into a straight line by plotting length at age $n + 1$ against length at age n. This was shown to apply commonly (but not always) to the growth of individuals of various types of organisms from clams to man, as well as to averages of groups of individuals in a population.

Walford (*op. cit.*) derived two "growth characteristics," the same as the slope and the "limiting value" derived by Ford from the regression equations. These characteristics, descriptive of the growth of different organisms, he designated as k, the slope of the transformation line, and $l\infty$, the asymptotic limit of growth. The constant k is less than unity and represents an average ratio of successive growth increments to the increment of the preceding year. It is a measure of the rate of deceleration of growth:

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[1] Published by permission of the Director, Fish and Wildlife Service, U. S. Department of the Interior.

$$k = \frac{l_n - l_{n-1}}{l_{n-1} - l_{n-2}}$$

The value $l\infty$ is the length at which the decelerating growth rate approaches zero and is determined by dividing the y-intercept of the transformation line by the complement of the slope.

Tåning (1944) has shown that experimental proof may be obtained as to whether a certain habitat form is genotypic or phenotypic. If growth characteristics are phenotypically plastic, one might look for their modification with alteration of single factors in the environment.

Preliminary to the application of Walford's graphic technique to the study of pilchard growth, it has appeared desirable to test experimentally the effects on growth of rather small differentials in environmental factors. For this purpose an ovoviviparous aquarium fish, *Platypoecilus maculatus* (Günther), of one genetic strain, has been studied. The stock was of the variegated type said by Innes (1944) to be similar to the common wild types native in southern Mexico. These fishes could be measured exactly (the lengths not merely estimated from scales) at regular intervals. Walford noted that the usual growth curves are difficult to compare and classify. His graphic method of treating that part of the curve above the inflection point, which can be approximated by a straight line, has been applied to these data.

To test the effect of establishing a differential with respect to one environmental factor, temperature, on the growth characteristics of *Platypoecilus maculatus,* a single brood of 45 was divided into approximately equal parts and placed in two 15-gallon aquaria. Whether growth characteristics, like certain meristic characters, are determined during the limits of a particular ontogenetic fixative or formative period (after which the characters remain virtually set) is not known for this species. Likewise it is unknown to what extent there is lability in growth characteristics after "birth" in such ovoviviparous fishes. The present experiment tests only the extent to which such modifications occur in response to a reasonably constant temperature difference in the two halves of the brood when separated two and a half days after birth.

The helpful interest of those persons who have been in charge of the U. S. Fish and Wildlife Service South Pacific Fishery Investigations, Mr. O. Elton Sette, Dr. Lionel A. Walford, and Mr. John C. Marr, is gratefully acknowledged. I also wish to thank Dr. Willis H. Rich who has read a first draft of the manuscript and offered constructive suggestions. Thanks are also due Mr. E. Frederick Smith, collector for the department of biological sciences at Stanford University, who kindly furnished a large brood of platies which were born in his laboratory.

METHODS

Temperatures in two aquaria, tank A and tank B, were maintained by two heating units regulated by thermostats. Readings, made at approximately 9 o'clock each morning on week days, gave mean temperature for the duration of the experiment (19 months) of 22.1° C. (71.8° F.) in tank A and 23.4°

C. (74.2° F.) in tank B; an average difference between the two tanks of 1.3° C. (2.3° F.) The standard deviations of the average weekly temperatures was 2.8° C. for tank A and 2.9° C. for tank B. Confidence limits for the means at the 95% level lie between 21.5° and 22.7° for tank A, and 22.7° and 24.1° for tank B.

In the experience of aquarists (Innes, *op. cit.*) *Platypoecilus* endures a temperature range of 65° to 90° but does best at about 74° F. The thermal tolerances of platies, such as those described for other fishes by Fry (1947), have, so far as I know, not been determined. The rather small temperature differential maintained in the two experimental aquaria is of the same order as that in nature and considered to be accountable for meristic variability in certain species of fishes.

An effort was made to keep constant all environmental factors other than temperature, although undoubtedly there were secondary effects introduced due to the temperature differential. The aquaria were provided with "seasoned" water and were planted initially with nearly the same complement of water plants, mostly *Sagittaria*. Pond snails, both *Physa* and *Planorbis*, were plentiful. Supplementary air, introduced by means of a small electric pump, was regulated by needle valves and entered the water through an air-stone. The aquaria were kept in a dark-room, and uniform light was provided 24 hours a day by two 25-watt incandescent bulbs. The volume of water was the same in both tanks, and to the extent that water evaporated, aged tap water was added. The pH, tested colorimetrically, remained close to 7.6 throughout the course of the experiment.

The young fish used in the experiment were born on the morning of March 23, 1946. The temperature of the aquarium at the time was approximately 23° C. On March 25 half of the brood was placed in each aquarium. The intention was to supply food in maximal quantity to both tanks. Prepared, dry "tropical fish food" was powdered and given as often as twice daily. The kind of live food was determined by the available supply, and the quantity by the amount that would not foul the water. Somewhat greater amounts were given to the fish in the warmer tank B because of the higher metabolic rate to be expected at a higher temperature. Pond plankton, white worms, scraped beef, *Artemia* nauplii and later the adults, served as sources of fresh protein. To what extent small fish also served this purpose is unknown. The first newly born fish of a second generation were noticed in tank A in the twenty-first week. No newly born fish were seen in the warmer tank until after the termination of the experiment, when a single pair of adults was left and produced young.

Food as a factor in the environment was further complicated by the initial higher mortality in the warmer tank B (Table II), and recruitment in the population of tank A. After the appearance during the fifth month of young in tank A, equal quantities of food were given to the two sets of fish. Each month when fish were measured the new recruits were removed from tank A.

Development of such inequalities in the two populations due to effects of mortality and recruitment might also affect space as a limiting or controlling factor in the two environments.

Measurements of the two sets of fish were made at monthly intervals from the first to the nineteenth months. Fish were anaesthetized in a weak chloretone solution of 1:2,500 concentration, recommended by Dr. Frederick Fish as relatively non-toxic. Fish were left for two or three minutes in this solution, or until quiescent, and were then removed with a small dipper to a metal measuring trough. This trough, designed and loaned by Dr. Willis H. Rich of Stanford University, had a vernier scale which permitted measurement to the nearest 0.1 mm. of total length. The fish were then transferred to a small net, where the remaining solution drained off, and returned to their tanks.

Inaccuracies in measurement, due to personal error, undoubtedly occurred. Other inaccuracies were sometimes caused by muscular contraction of a fish that interfered with its lying perfectly flat in the measuring trough.

Sex Ratios

Sexes were ascertained as far as possible, at the time of measuring. Secondary sex characters began to appear as early as the second month, and were clearly evident in the fourth month; by the sixth month nearly all fish were apparently mature. Previous to the time when sexes were readily distinguishable, probable sex groupings were approximated by extrapolating growth curves of individual fish. Sex ratios in both tanks showed early predominance of males, although by the ninth month in the warmer tank B, and somewhat later in tank A, the percentage of males became less than that of females (Table I). The ratios continued to be higher for females in both tanks.

Table I

Sex Ratios of *Platypoecilus* in Tanks A and B, 1945 Brood

Months	Tank A				Tank B			
	Males		Females		Males		Females	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
4	10	45(67)*	5	23(33)*	10	62	6	38
5	13	59	9	41	9	60	6	40
6	11	55	9	45	8	57	6	43
7	9	50	9	50	8	57	6	43
8	9	50	9	50	7	54	6	46
9	9	50	9	50	4	40	6	60
10	..	..	..	..	..	..	..	..
11	6	40	9	60	4	40	6	60
12	6	43	8	57	4	40	6	60
13	6	43	8	57	3	33	6	67
14	6	43	8	57	3	33	6	67
15	6	43	8	57	2	29	5	71
16	5	45	6	55	2	33	4	67
17	4	44	5	56	2	40	3	60
18	4	44	5	56	2	40	3	60
19	4	44	5	56	2	40	3	60

* Percentages in parentheses are of those individuals sexed; among the 4-month fish in tank A, 7 fish (32 per cent) were immature and not sexed.

Estimates of Growth of Individuals

As soon as individuals could be sexed it was possible to follow with a reasonable degree of certainty the subsequent growth of a particular fish. Lines connecting a series of measurements would approximate the course of individual growth. Previous to the time when sex could be ascertained, however, the probable course of growth was estimated by connecting the earlier most likely measurement, representing the "best guess" for each individual. Such extrapolation of individual curves was made back to the fourth month. By this means it was possible to follow the growth of those individuals which survived throughout the course of the experiment, and thus to obtain a closer approximation to a "true" growth curve for each sex. The advantages in avoiding effects of mortality on later measures of mean growth were felt to outweigh the obvious difficulties in such estimates.

MEAN GROWTH AND VARIABILITY

Table II presents the data on variability in total length of fish (males and females combined) in the two tanks. Additional data on platy variability are given in Table III for a small brood (born on November 15, 1945) of the same genetic strain, kept for 18 weeks in tank B before the large brood was obtained. The coefficient of variation is considerably less for the small brood and may be associated with early selective mortality. The larger brood was born under conditions that probably favored maximal survival, i.e., when live pond food was abundant in the tank and the chances of being eaten by the parents were small.

TABLE II

VARIABILITY IN TOTAL LENGTH OF *Platypoecilus* IN TANKS A AND B, MEASURED AT MONTHLY INTERVALS, 1946 BROOD

Months	Number of fish		Mean length (in mm.)		Standard deviation of combined lengths of the sexes		Coefficient of variation (in %)	
	Tank A	Tank B	Tank A	Tank B	Tank A	Tank B	Tank A	Tank B
1	22	18	18.1	17.8	3.35	2.40	18.5	13.5
2	22	17	26.7	25.4	5.00	3.35	18.7	13.2
3	..	..	....	....	....	....	....	....
4	22	16	31.4	29.4	4.45	4.20	14.2	14.3
5	22	15	32.4	30.7	4.80	4.05	14.8	13.2
6	20	14	33.1	31.6	4.95	4.30	15.0	13.6
7	18	14	34.1	32.3	5.30	4.45	15.5	13.8
8	18	13	34.8	32.8	5.55	5.00	16.4	15.2
9	18	10	35.6	35.2	5.70	5.30	16.0	15.0
10	..	..	....	....	....	....	....	....
11	15	10	38.2	37.2	5.30	5.60	13.9	15.0
12	14	10	38.4	38.3	5.20	5.90	13.5	15.4
13	14	9	39.0	38.3	5.35	6.30	13.7	16.4
14	14	9	40.0	38.5	6.00	6.40	15.0	16.6
15	14	7	40.7	39.5	6.30	6.40	15.5	16.2
16	11	6	41.2	39.8	6.80	5.95	16.5	14.9
17	9	5	42.1	38.1	6.40	6.00	15.2	15.7
18	9	5	42.5	38.4	6.45	6.25	15.2	16.3
19	9	5	42.7	38.6	6.75	5.80	15.8	15.0

From the average of individual measurements, mean growth curves were estimated (Fig. 1) for all males and females in each tank. Estimates for standard deviations (S) of the average length of each sex at each month of life were made using Snedecor's (1948) table of ratios, range/σ. A further estimate of standard error ($S_{\bar{x}}$) was then used together with a table for values of t (reprinted in Snedecor, *op. cit.*) to obtain the confidence limits of these means at the 5 per cent level of probability. Some aberration in these curves is attributable to mortality of certain individuals; for example, loss of a particularly large male or female is reflected in a marked drop in mean sizes thereafter.

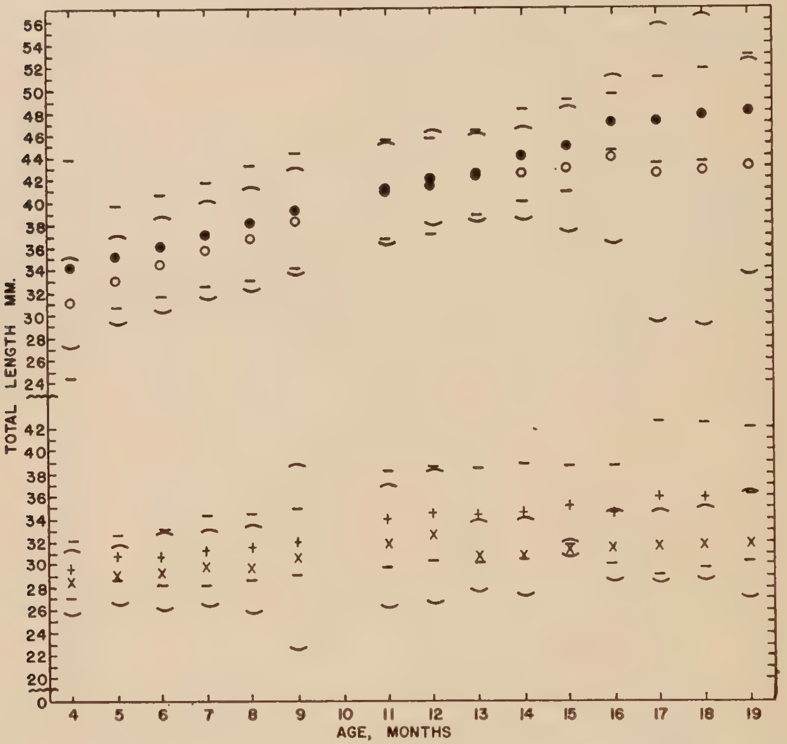

Fig 1. Average size at the end of each month of life of females shown by • for tank A, by ° for tank B; of males shown by + for tank A and by × for tank B. Confidence limits for tank A means indicated by =, for tank B by ⌢.

In order to avoid such effects of mortality on descriptive measures of growth in the two sets of platies, growth from the fourth month of only those males and females which survived to the end of the experiment is plotted (Figs. 2 and 3). The higher mortality of males results in a measure of male growth in tank B being based upon only two individuals. However, this is the best measure obtainable.

Application of Walford's Method of Transformation to the Growth Curves of *Platypoecilus*

It may be useful to know for comparison within fish stocks of commercial importance what order of variability in growth characteristics is found within one genetic strain of a species when comparable groups are subjected to some alteration in their physical environments.

The growth characteristics of one genetic strain of platies exhibit striking stability with respect to rate of deceleration of growth (k) as shown in the

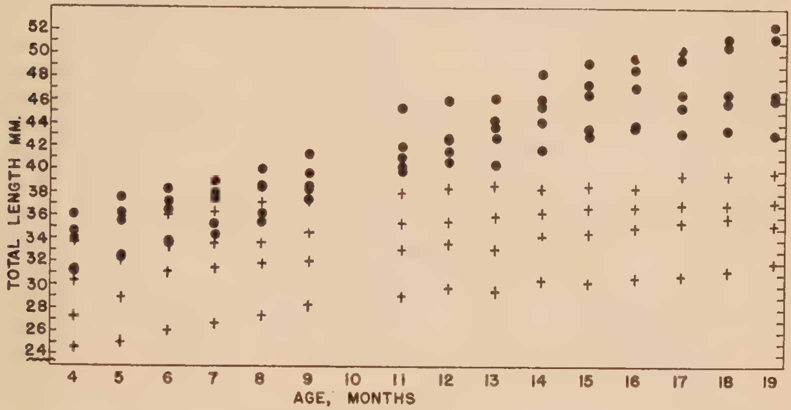

Fig 2. Lengths from the fourth month of life of males and females which survived to the end of the experiment in tank A. Males indicated by +, females by •.

TABLE III

VARIABILITY IN TOTAL LENGTH OF *Platypoecilus*, MEASURED AT WEEKLY INTERVALS, 1945 BROOD

Weeks	Number of fish	Mean length (in mm.)	Standard deviation of combined lengths of both sexes	Coefficient of variation (in %)
2	13	11.8	0.36	...
3	13	13.6	0.34	...
4	13	15.0	0.56	3.7
5	..	....	....	...
6	..	....	....	...
7	10	17.5	0.66	...
8	10	18.7	0.70	3.7
9	10	20.4	0.54	...
10	10	22.3	1.07	...
11	10	24.6	1.00	...
12	10	26.5	1.03	3.9
13	10	27.9	0.95	...
14	10	29.0	1.16	...
15	10	30.0	1.25	...
16	10	31.0	1.39	4.5
17	10	31.8	1.36	...
18	10	32.6	1.80	...

slopes of the following regressions. At the same time there is wide latitude of variation in absolute size at any age, and in the males as compared with females, as well as some variation in their asymptotic limits of growth. This contrast in

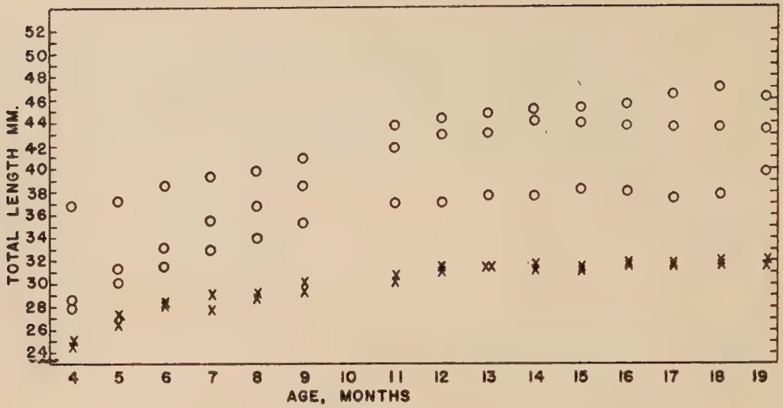

Fig. 3. Lengths from the fourth month of life of males and females which survived to the end of the experiment in tank B. Males indicated by ×, females by °.

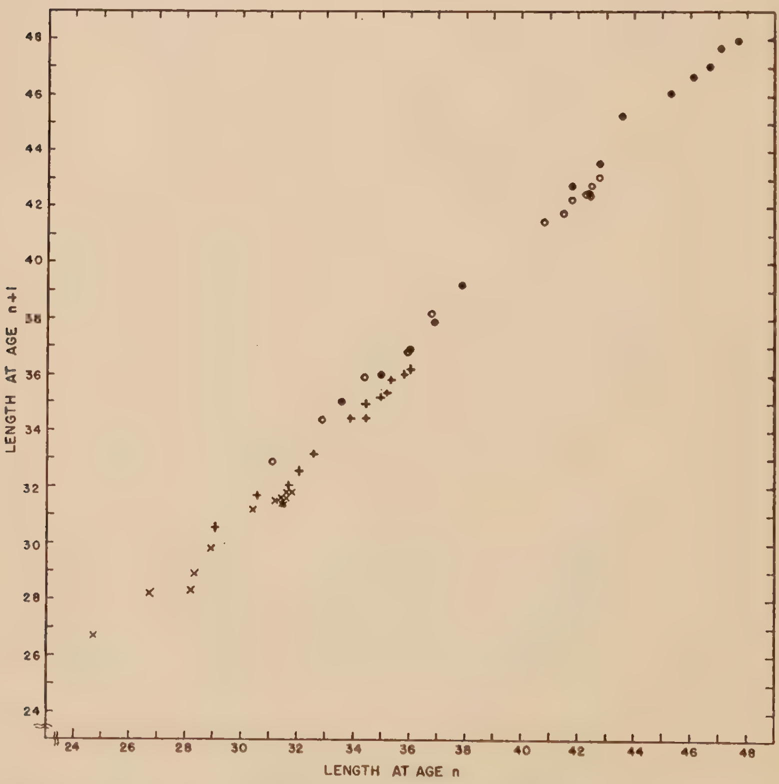

Fig. 4. Transformations of the mean curves of growth of males and females surviving to the end of the experiment. Average sizes of males in tank A indicated by +, females by •. Average sizes of males in tank B indicated by ×, females by °.

plasticity with relative stability in the growth characteristic (k) suggests that phenotypic variability may prove to be distinguishable from genotypic difference.

Figure 4 shows transformations of the curves of growth for the fish in tanks A and B. The points plotted are the mean lengths of those males and females that survived to the end of the experiment. These curves illustrate the relative constancy in rate of deceleration of growth expressed by the slope of the regression line. Regardless of actual size attained at any given age, the percentage increments in successive equal time periods show the constant ratio of a geometric series. Thus, although females grow much faster than males and probably achieve a considerably greater length, the percentage ratio that each increment represents of the one preceding is closely similar for both sexes. This relation also holds in comparing fish of lesser mean absolute sizes at any given age (whether males or females) in the warmer tank with those of greater size in the cooler tank. The rate of deceleration remains nearly the same and variability in absolute size is expressed, as in males and females in one tank alone, by difference in position along the more or less constant regression slope.

Such minor differences as do exist in these two pairs of transformations (Table IV) may be associated in some degree with the small, relatively constant temperature difference in the two tanks. Both males and females in the warmer tank show somewhat more rapid rates of deceleration and lower asymptotic limits of growth. Unfortunately no comparable control tanks were available to further check these effects, and no measure of variation due to chance alone was obtained.

Transformations of growth curves for individual fish follow a geometric progression rather closely. Growth of four platies, the smallest and largest of the males and of the females that survived throughout the whole period of observation in tank A, is plotted in Fig. 5. Again, despite widely differing absolute values, the ratio of successive increments remains nearly the same. The four curves together trace an almost straight line and further illustrate the relative stability of the growth characteristic k.

Two small broods of platies of the same genetic strain as the large brood were maintained for a short period in the same tanks A and B, and supplement the data of the main experiment. Six fish were born October 8, 1945, in tank B; thirteen were born November 15, 1945, in tank A. The latter brood was reduced to ten due to an accident that occurred in both tanks in December. Except for this interval when fish were transferred to other tanks, they were measured weekly beginning with the first week in tank B, the second week in tank A. Temperature conditions were similar to those prevalent during the period of experiment with the large brood but with less difference in the temperature levels in the two tanks. The small broods were given a somewhat different diet from that of the large brood as the attempt was not made to supply food in maximal amount.

Mean growth curves for males and females combined are shown in Fig. 6 for the two small broods as compared with the two halves of the larger brood. Differences in the first stages of growth may be attributed largely to the lesser food supply available to the smaller broods.

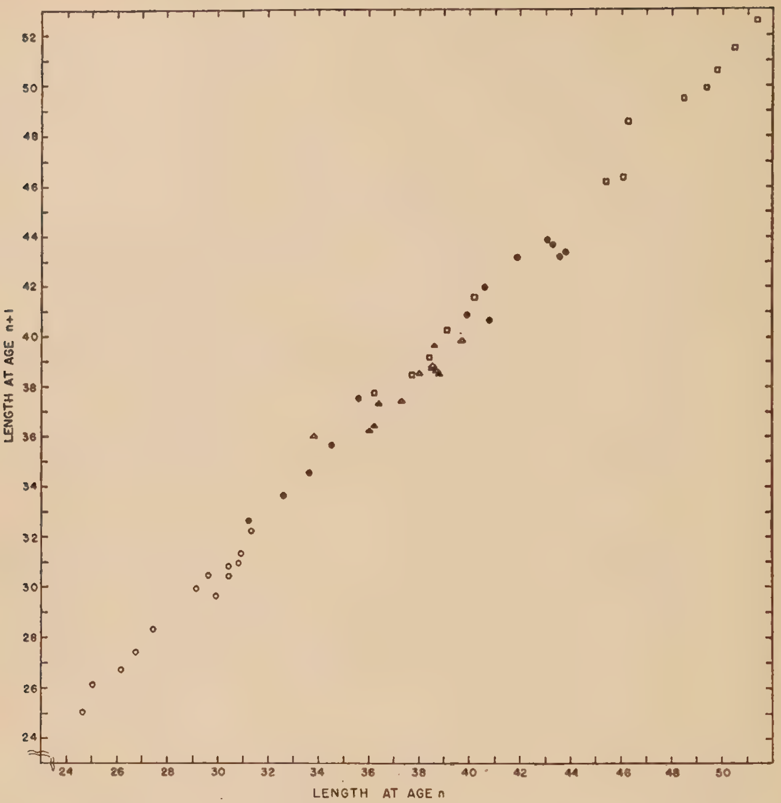

Fig 5. Transformations of growth curves of the smallest and largest male and female individuals that survived to the end of the experiment in tank A. Smallest male indicated by ○, largest male by △, smallest female by •, largest female by □.

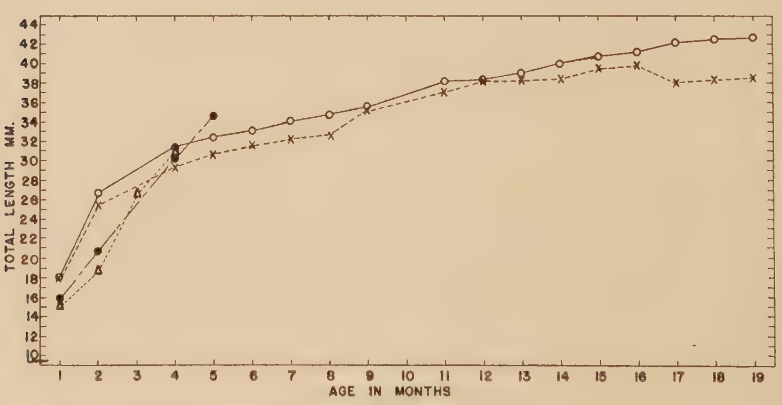

Fig 6. Mean growth curves of *Platypoecilus maculatus,* males and females combined. Average sizes of half of the large brood in tank A shown by ○, of the half in tank B shown by ×. Average sizes of a small brood of six shown by •, of another small brood of ten shown by △.

When average growth for all three broods is plotted in transformations (Fig. 7), mean growth for males and females combined suggests a similar percentage rate of deceleration in the small broods and in the two sets of the larger brood. The constancy of slope maintained in different environments seems to indicate that the growth characteristic *k* is a genotypic character, while differences in the level of these transformation lines probably represent phenotypic variation. In the large brood, mean growth beyond the inflection point is represented satisfactorily by the transformation curve. The deviation of the first points from these two regressions indicates that the transformation cannot be applied to that part of the usual growth curve below the inflection. (Transformations in Figs. 4 and 5 include only sizes subsequent to the first period of rapid growth.) For the two small broods maintained only until weeks 18 for one, and 23 for the other, mean growth is plotted by the 4-week time interval equivalent to that used for the larger brood. It is not clear from either the conventional plot (Fig. 6) or the transformation (Fig. 7) at what time the inflection point of the length-on-time curves appears for the small broods. When, however, such curves are plotted showing weekly, rather than monthly, increments in size there is an indication that for smaller broods inflection occurred at an earlier age so that their transformations properly may be compared with those of the two sets from the larger brood.

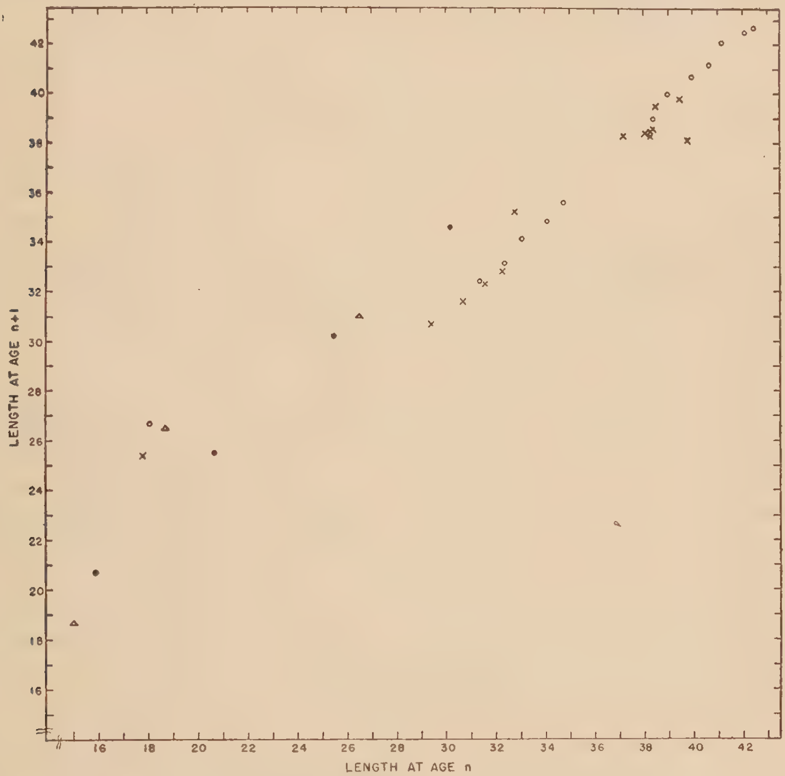

Fig 7. Transformations of mean growth curves shown in figure 6.

Calculated Growth Characteristics

Walford (*op. cit.*) suggested that the growth characteristics k and l_∞ could be used for studying growth variation within and between populations, and hence for distinguishing between races of animals with differing growth patterns.

In commercially important species, individuals often do not become fully available to the fishery until after they have passed the point of inflection. In populations of food fishes the growth characteristics may be derived (from calculated lengths of fish) without recourse to graphic treatment, and are provided, in effect, from a fit of the linear regression of lengths at ages $n + 1$ on n. The two constants for the linear equation of the type $y = a + bx$ were obtained by the method of semi-averages.[2]

This is equivalent in Walford's notation to the equation,

$$l_{n+1} = l_1 + k\, l_n$$

and also yields an estimate of asymptotic length,

$$l_\infty = \frac{l_1}{1-k}$$

These constants are then applicable to the phase of growth following the inflection.

The two growth characteristics, deceleration rate (k) and asymptote (l_∞), are given in Table IV. These were calculated for average growth of each sex, for certain individuals, and for the sexes combined, in the two sets of platies discussed above. For the two small broods growth characteristics are estimated for males and females combined.

For the larger brood the small calculated ultimate size of males reflects the sex dimorphism in size observable in platies from the time of appearance of secondary sex characters. In general, the rates of deceleration are also somewhat more rapid in males. An inhibitory effect of higher temperatures on growth is suggested in lesser symptotic lengths as well as more rapid deceleration rates for both sexes in the warmer tank. The two small broods show the slowest deceleration rate and highest calculated ultimate size.

Asymptotic levels vary widely and are sometimes improbably high for the species. Deceleration rate, however, is the growth characteristic showing the most stability, varying only within rather narrow limits, as is revealed also in the graphic treatment of the platy growth data.

It was found both for the platy data and for the growth characteristics of one year-class of pilchard that when growth characteristics are plotted as a regression of asymptotic length on slope, the relationship is curvilinear rather than rectilinear. The values for asymptotic length increase very rapidly at the higher values of k when rate of deceleration in growth is very slow.

Conclusions

Irrespective of the initial period of rapid growth, it appears that beyond the inflection point the rate of deceleration of growth, as shown by the slope of a transformation line, is relatively constant for this genetic strain of platies. Within the limits of the experiment the rather consistent slopes or deceleration rates hold, both for different metabolic rates, as under slightly different temperature conditions, and in different sexes and, in all probability, at different levels of food intake as well. The growth characteristic k thus may be useful as a physiological character descriptive of a population of fishes.

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[2] This method in lieu of "least squares" was recommended by Dr. Walford for use in calculating growth characteristics of pilchard from scale data. Aside from its simplicity when applied to large numbers of individuals, the method may have an additional advantage in that, if the first point in the transformation curve were sometimes influenced in a non-random manner, owing to possible inclusion of a segment of the growth curve preceding the inflection point, the effect would be minimized.

TABLE IV

GROWTH CHARACTERISTICS OF THE TRANSFORMATIONS OF THREE BROODS OF *Platypoecilus maculatus*

Brood and Measurement	Tank	Sex	Slope k	Y-intercept	Asymptote
3/23/46 brood of 45 fish; growth measurements from the 4th to 19th month					
Transformations of:—					
Mean lengths of all individuals	A	Male	0.92	3.2	38.6
		Female	0.99	1.5	107.0
	B	Male	0.72	8.8	31.6
		Female	0.84	7.1	44.4
Mean lengths of individuals which survived to end of experiment	A	Male	0.88	4.7	37.6
		Female	0.95	3.0	60.0
	B	Male	0.79	6.7	31.6
		Female	0.83	7.3	44.0
Lengths of 4 selected individuals which survived to end of experiment	A	Male #1	0.94	2.1	37.5
		Male #4	0.83	6.6	39.8
		Female #1	0.89	5.0	45.6
		Female #5	0.96	3.1	68.8
Mean length of all individuals	A	Male and female	0.92	3.7	46.3
	B	Male and female	0.85	6.1	40.1
10/8/45 brood of 6; growth measurements from the 1st to 23rd week					
Transformations of mean lengths of all individuals	B	Male and female	0.99	1.3	162.5
11/15/45 brood of 10; growth measurements from the 2nd to 18th week					
Transformations of mean lengths of all individuals	A	Male and female	1.00	1.3	l_∞

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THE POSSIBLE IMPORTANCE OF OTHER VERTEBRATES IN SARDINE INVESTIGATIONS

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South Pacific Fishery Investigations, Stanford, California

The recent decline in landings of the pilchard or sardine, *Sardinops caerulea* (Girard), 1945, along the Pacific Coast of North America has demonstrated the need for a greatly expanded research program, if such events are to be understood (Marr and Widrig, MS). This decline has, in fact, given rise to an expanded cooperative program involving the California Academy of Sciences, the California Division of Fish and Game, the Scripps Institution of Oceanography, and the South Pacific Fishery Investigations of the U. S. Fish and Wildlife Service. The fishing industry is actively participating through the Calfornia Marine Research Committee. Financial support has come from a special tonnage tax on sardine landings, through appropriations of the California Legislature, and from the already existing budgets of the several agencies.

The integrating theme of these investigations is a common interest in the productivity of the Pacific Ocean off the West Coast (roughly that area from the Columbia River on the north to central or southern Lower California on the south and up to 400 miles offshore). More detailed information on the organization and progress of this work is presented elsewhere (Cal. Acad. Sci., *et al,* 1950; McHugh and Ahlstrom, In Press). It is our desire to consider some of the ecological aspects of fishery research and especially to consider the possible importance of other vertebrates in a study of the sardine. (We exclude man from ''other vertebrates,'' since the effect of man's activities on the sardine is already the object of considerable study.)

Of immediate and basic interest in sardine studies are causes of fluctuations in abundance. Such fluctuations may be real and be the result of greater or lesser than average spawning success or the result of increases or decreases in the mortality rates of adult fish. Or fluctuations may only be apparent and the result of greater or lesser availability of the fish to the fishermen. Understanding of this problem calls for study of the dynamic physico-chemical, and biological processes going on in the general region of survey.

Declines in the landings of clupeoid fishes are known to Europe in the past, and more recently have occurred in Japan, Korea, Russia, Africa, Peru, and Portugal. The known presence of a fungus disease in the Atlantic herring, *Clupea harengus* Linnaeus 1758, is suggestive

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[1] Published by permission of the director, U. S. Fish and Wildlife Service.

(Scattergood, 1948). If the patent explanation of these declines were a pandemic among clupeoid species, the hidden cause of its spread might still be found by exploration of the environments in which it flourished. Some hint of the importance of the environment is suggested by experiments of Snieszko (1938) on carp in which he has determined that antibodies are formed only at relatively warmer temperatures. In a cold environment no antibodies were formed.

The study of a region or area as more or less of a unit is also desirable from the oceanographic point of view. Defant (1950:1) states: ''I should like to emphasize that this large collection of observations taken off the California coast at monthly intervals over a period of several years has extraordinary significance from a scientific point of view. At the meeting of the International Association for Physical Oceanography in Edinburgh in 1936, the next goal of physical oceanography was emphasized: the systematic synoptic investigation of smaller ocean regions. Only thus should we be able to obtain insight into the dynamics of the oceanographic processes.''

This ecological, areal approach is coming to be more widely held by fishery biologists and the facilities making such views realistic are now often in hand or in sight. From investigations of single species, often of necessity land based and dependent largely on vital statistics obtained from samples of the commercial catch, studies have broadened to include the whole environment. Such fishery biologists as Dr. W. M. Chapman, Mr. O. E. Sette, and Dr. L. A. Walford have been influential in advancing this approach. Among the oceanographers, Dr. H. U. Sverdrup has been foremost in realizing the needs in fishery investigations of advances in oceanography. The interests of fishery biologists and oceanographers must often be identical or at least widely overlapping.

One perhaps unique aspect of sardine studies is the interesting, although rather qualitative, data being collected on the occurrence of marine birds and mammals. The role of such vertebrates in the food cycle is multiple. They may be predators on sardine, or they may prey on sardine predators or on sardine food. They may compete for space. Through their waste products they must be important in returning organic material to the lower part of the cycle, within the euphotic zone. They may prove useful in serving as indicators of particular water masses or regions of high productivity. Although not germane to the present area or problem, the association of porpoises and tunas in tropical waters is intriguing and little-known.

Early in plans for work at sea it was suggested by Dr. C. L. Hubbs and Dr. J. L. McHugh that systematic observations be made on the distribution and abundance of mammals and birds. Through the courtesy of Dr. Hubbs the records of mammals seen by observers on regular monthly cruises of the U. S. Fish and Wildlife Service vessel *Black Douglas* and Scripps vessels *Crest* and *Horizon* during 1949 and 1950 have been made available to us. These data await his more complete analysis, but certain observations are of interest here.

The distribution of whales, for example, has previously been known mostly from the records of whaling ships, and the following species have been commercially important in the Pacific: Sperm, northern and southern rights, bowhead, blue, finback, Sei, humpback and gray whales (Orr, 1940). Orr (1940:219) further states that "Most of the larger species of whales which are now used commercially are circumpolar in distribution, hence data regarding their latitudinal limits are in a rather general way applicable to the species in all oceans in which they occur. Ocean currents do, however, modify their distributional limits in many areas."

The toothed whales observed in the area of survey were relatively offshore; killers (*Grampus rectipinna* (Cope)), off Cape Mendocino, a large school of blackfish (*Globicephala scammonii* (Cope)), off Lower California, and a sperm whale (*Physeter catodon* Linnaeus) southwest of Cape Mendocino. The baleen whales, blue (*Sibbaldus musculus* (Linnaeus)), finback (*Balaenoptera physalus* (Linnaeus)), Sei, *B. borealis* Lesson, humpback (*Megaptera novaeangliae* (Borowski)), and gray whales (*Rhachianectes glaucus* (Cope)) have all been observed, although not in large numbers. Most of the records of whales were relatively inshore, from south of Cape Mendocino to northern Lower California. A few were recorded off Oregon in August, September, and November. To date, there are records of 60 unidentified whales. The bowhead and north right whale are said to be "so rare as to verge on extinction" (Fish, 1949:54-55).

According to Fish (1949:39), Dr. C. L. Hubbs has made some tests with sonar as an aid in studies of the migration of gray whales. In the course of their work on sardines, using echo-ranging and echo-sounding equipment, it is possible that the California Division of Fish and Game may also accumulate data on mammals.

The majority of observations of porpoises are inshore between Cape Mendocino and Pt. Conception. There appeared to be a tendency for more schools to be present off central California from February to June. None were observed in July or October. In August, September, and November they were seen more frequently off northern California and Oregon. In some instances they were recorded far offshore. Schools of Dall porpoise, *Phocoenoides dalli* (True), were seen in May and November well off Lower California. Two small schools of an unidentified species were seen off San Diego in September. In November, January and March, schools were observed inshore off central Lower California. This is the only area in which large schools of "beaked porpoise," presumably a southern species, were noted. The striped dolphin, *Lagenorhynchus obliquidens* Gill, was seen only to the north of San Francisco.

Observations of fur seals, of which there are several hundred, are rather more abundant inshore than offshore and extent from northern Lower California to northern California. Most records are from central California from February to May. Since fur seals, *Callorhinus ursinus alascanus,* haul out on the Pribilof rookeries beginning in June, this suggests that these May records may be of young cows which do not reach the Pribiloffs until late summer. Chapman (1947) has suggested that the fur seals must consume, as a minimum, 3.5 billion pounds of fish, squid, etc., annually. This exceeds the total commercial production of the region from the Bering Straits to the Galapagos Islands. Presumably most of this total is consumed at sea, away from the Pribilof Islands.

There are also present off California herds of Steller sea lion, *Eumetopius stelleri,* and California sea lion, *Zalophus californianus.* According to annual censuses made in the June and July breeding season, the sea lion population off the California Coast has remained relatively stable over a 20-year period (Bonnot and Ripley, 1948). They report 8,716 animals for the 1947 census, although the previous 5-year average was a little over 7,000, and they suggest that the 1947 estimate may represent the effects of improved coverage. More recent evidence has been given of a considerable increase in numbers on some of the Channel Islands (Bartholomew, Collyer, and Dawson, 1951). These sea lions must consume at least 9.5 million pounds of fish, mollusks, etc., annually.

For both the fur seals and sea lions it is likely that these amounts are in addition to, rather than in competition with, the commercial production of the area (Chapman, 1947; Bonnot, 1928).

McHugh (1950) has reported on the occurrence of the blackfooted albatross, *Diomedea nigripes,* Audub., off California in 1949. The observations indicate that these albatross are more abundant than formerly and are found closer to the coast, perhaps as a result of increased abundance. Also according to McHugh (personal communication dated February 16, 1951), the center of abundance moved northward in the spring and southward in the fall. This was more pronounced in 1949 than in 1950. In 1949, the birds also seemed to shift from inshore in the spring to offshore in the fall. No offshore rend was noted in 1950. McHugh (1950) also records occurrences of he rare Laysan albatross, *D. immutabilis,* Rothsch.

There is some indication that the distribution of albatross may be ssociated with waters of high zooplankton content.

Dr. C. L. Hubbs has observed tremendous concentrations of sooty hearwaters, *Puffinus griseus* (Gmel.), feeding on small fish close inhore off Lower California. Such feeding could cause large local ortalities. The "guano" cormorants of Peru are known to consume normous quantities of fish.

These miscellaneous observations should emphasize that birds and ammals form an important part of the marine environment. In any cological study, whether it be with reference to a particular species f fish or to a particular area, the importance of other vertebrates s not yet known. The relationship of birds and mammals to the flucuations in abundance of sardines may prove to be a direct and close ne, or it may prove to be indirect and removed. It may well be of a ature not yet considered.

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DISCUSSION

DISCUSSION LEADER UNDERHILL: Thank you, Dr. Felin. Are there any questions on this approach on the ecological relationship of the various vertebrates to the fishery resources off our coasts? I think that this opens up a field which certainly needs a great deal of further investigation.

CHAIRMAN WALLACE: I would like to make a comment. It seems to me that these marine mammals and the birds which have been mentioned here are an important factor in the over-all chain of life in the sea. If the figures that are quoted in this paper as to the amounts of fish consumed are even close to being accurate, it means that there is a tremendous drain which is going off into these channels, and certainly it must have a significant bearing on the over-all productivity of any given species, and might have some bearing on the total sardine population.

MISS FELIN: Dr. Chapman figured the consumption of fish and mollusks of fur seals by noting what they ate at the zoos and aquariums, and I think that he also figured that the fur seals don't eat while they are on the breeding grounds, so we figured that the sea lions would be similar.

THE EELS OF THE NORTHERN GULF COAST OF THE UNITED STATES AND SOME RELATED SPECIES

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INTRODUCTION

This paper is a continuation of studies carried out on the fishes of the northern Gulf coast of the United States. The last account of the eels of this region in a single publication, was included in a paper published nearly 60 years ago by Jordan and Davis (1891). The present paper brings the account up to date and describes some new species.

The specimens on which this paper is based are chiefly from five sources: those in the U. S. National Museum, and the Museum of Comparative Zoology; those collected by the "Atlantis" in 1937 and now deposited in the Bingham Oceanographic Collection; those obtained by the U. S. Fish and Wildlife research boat "Pelican" during 1938-40; specimens obtained by the Texas Game, Fish and Oyster Commission and sent in by Mr. J. L. Baughman. I wish to express here my gratitude to the authorities of these institutions who granted me the privilege and the free use of their facilities to pursue these studies.

The geographic limits with which this paper deals are from the Rio Grande to the region between Cape Romano and Cape Sable, Florida. The species recorded from, or those which have been found to occur in this stretch of the coast during this investigation, are here treated. The Florida Keys are not included. The fish fauna at the Keys is different, being, by and large, similar to that of the West Indies and Central America.

Three extra-limital species are included. Two are from the Atlantic coast of the United States, one obtained by the Pelican, the other by the Albatross, both representing a new genus and species and encountered during the present comparative study. The third species, *Gymnothorax ocellatus* from Brazil, is included for comparative purposes, because two Gulf species often have been identified with it.

The main object of this paper is to elaborate the external characters by which the species in the region concerned may be distinguished and readily identified. While the species have been compared where necessary and available with those from other regions to establish their identity, no attempt was made to revise the families or genera to which they belong. As this paper does not represent a revision of the genera on a world wide basis, the given generic definitions include only the characters common to the species here treated, and they are not repeated under the species accounts. For the same reason, no attempt was made to compile a complete synonymy or bibliography to the genera and species. As a further consequence, the complete geographic distribution of every species was not determined from records in the literature. However, in most cases all available specimens were examined, including those from extra-limital localities, and the entire geographic distribution of the specimens examined is stated under the accounts of the species.

The classification of eels into families is at present in a state of flux, and it is difficult to decide for the purposes of a faunal study of a limited number of species, such as this paper is, their proper allocation by family. The number of apodal families has been gradually increased by authors. By this process of subdivision, each family comes to comprise one, or a small number of genera that are more nearly related. On the other hand, in general, this process lends itself readily to continued expansion until a point may be reached where the family as a convenient unit in classification loses a great deal of its usefulness. It appears that this point has been reached and exceeded with respect to the classification of the eels adopted by a number of authors. The number of apodal families that have been proposed, which contain but one or two or a small number of genera form a large percentage of the total, strikingly more so than in other orders or suborders of fishes that are now in an active stage of speciation, that is, excluding relict or otherwise exceptional orders. This excessive splintering of the families does not seem to represent a real advance in the classification of Apodes. Certainly from the standpoint of convenience too many eel families have been proposed.

Without attempting a complete historical review of family subdivision of the Apodes, the following two authors who present the most comprehensive outline of the subject are here briefly discussed. Regan (1912) in a short paper divides the order Apodes into 17 families. Trewavas (1932), after a study of "some rare eels" increases the number of families to 22. However, these authors leave some important questions unanswered. How many genera, in the few of their families that include a number of genera, have they studied? Do the characters that they use for separating the families differ from genus to genus, and if so, to what extent? Are the boundaries between the families sharply marked, or are some of the genera transitional as they often are in classification? Besides, the subfamily category is a convenient device often used in taxonomic practice which might be applied also in the classification of the Apodes.

The present stage of the subdivision of the Apodes into families being unsatisfactory, in this faunal account especially, which represents but a moderate segment of the total known number of genera and species of eels, it seems best for the purpose of convenience to hold down the number of families. Therefore, the species here treated are divided into 5 families. This in general, is in accord with that used by previous authors, with the following exceptions. According to Regan and also Trewavas, *Dysomma* and *Dysommina* should be placed in a separate family, Dysommidae; while *Hoplunnis* should probably be laced in the Nettastomidae according to the classification outlined by Trewavas. Workers who wish to pursue the division of groups of genera in greater detail, might divide the genera here assigned to the family Congridae, into three subfamilies, Congrinae, Nettastominae and Dysomminae. However, it would seem best to defer any such division until a thorough comparative study is made of these and related genera on a world wide basis.

Judged by the material forming the basis of this study, it is apparent that our present knowledge of the eels of the Gulf is fragmentary. (This statement applies to other regions as well.) Of about half the species here treated only one or a very few specimens have been collected so far, some of them taken from the stomachs of other fish. Some of the species have not been rediscovered since their original description, on the basis of one or two specimens, 60 years ago or so. Of the other species, excepting *Anguilla rostrata,* the number of specimens collected up to now is very moderate. This state of affairs is quite understandable. Eels living offshore are usually obtained by trawling. However, they are generally tenacious of life, and considering their shape and manner of locomotion, an eel finding itself in a trawl is able to wiggle its way out through the meshes of the net. It is only a luckless individual which is temporarily trapped by the mass of fish in the trawl, that is landed on deck. From the preceding premises, it seems reasonable to conclude that the number of species of eels which remain unknown, constitute a considerable percentage of the total number of living species.

DEFINITIONS

Terms applied to certain measurements used in this paper have the following significance.

LENGTH—total length, from tip of snout to posterior end of fish, including the caudal fin when present, which in eels is short and forms a virtually negligible part of the total length.

BODY—distance from tip of snout to vent.

TRUNK—distance from upper angle of gill opening to vent, or from its anterior angle when the gill opening is horizontal or oblique.

TAIL—distance from vent to posterior end of fish, including the caudal fin when present.

The above four measurements were made by stretching the specimen on a table, sticking vertically 4 ordinary dressmaker's pins in the table, at the two ends of the fish, opposite the upper or anterior corner of the gill opening, and at the vent, and measuring the distance between the pins by a steel tape graduated to millimeters. The measurements as actually made deviate somewhat from measurements taken on a straight horizontal line between verticals through those four points; but such deviation obviously is virtually negligible.

The following measurements were made with a Vernier caliper, except that the antedorsal was sometimes measured by means of pins as outlined above, when that measurement was long.

ANTEDORSAL—distance between tip of snout and origin of dorsal fin.

HEAD—distance between tip of snout and upper or anterior corner of gill opening.

UPPER JAW AND LOWER JAW—distance between the tip of either jaw and the corner of the mouth as observed externally. The latter point is not easy to determine with precision, and it also differs somewhat with the state of preservation of the specimens. Consequently, these measurements are only roughly approximate.

SNOUT—distance from its tip to anterior margin of eye.

EYE—horizontal distance between two vertical tangents, through anterior and posterior margin of eye, respectively. The outline of the eye is indefinite in some species, and the snout and eye measurements in such species are only very roughly approximate.

DEPTH—measured at a point just in front of vent, except where otherwise specified.

PECTORAL—distance on a straight line between the upper angle of its base and its tip.

CAUDAL—distance from its tip to end of last vertebra. This measurement is of moderate importance in distinguishing a few of the species from their relatives, and was determined only for such species.

MEASUREMENT—Figures for measurements given under each species refer to percentages of the total length, except when otherwise indicated. As proportional measurements change with growth, figures for measurements have been segregated into size groups where the material permitted, generally into two size groups. In such cases measurements of the smaller specimens are given in parenthesis. It is to be noted especially that one important measurement, that of the tail, generally decreases with growth, and conversely, the body increases. As the tail or body measurement is usually a good specific character, or even a generic character in a limited sense, it is important to correlate it with the length of the specimens measured.

DENTITION—The dentition is of much importance in the classification of eels, and is hereafter described under the various genera and species. On the roof of the mouth cavity, the teeth are roughly disposed in three series, as follows.

1. A bilaterally symmetrical series on the side of the upper jaw, consisting of one or more rows, depending on the genus or species. These teeth are hereafter described as jaw teeth.

2. A median series on the anterior part of the upper jaw, consisting of a single arched row, or of a patch of teeth. In the following descriptions the teeth in this series are designated premaxillary teeth.

3. A series on the midline of the palate, behind the premaxillary teeth, consisting of one or more rows, or a tapering band, or a patch of teeth. These are hereafter designated as palatal teeth. The latter term should not be confused with "palatine teeth" used in describing the dentition on the palatine bones of other fishes. What are designated as palatal teeth in this paper, are usually currently described by authors as "vomerine" teeth. However, the homology of the dentigerous bones in eels is still open to question, and the osteology of comparatively few species has so far been elaborated by workers to serve as a basis for general conclusions. Furthermore, the series of teeth on the palate differs in position with the species. Especially in some exotic species from the standpoint of this paper having jaws of ordinary length, the teeth on the palate are placed far back on the roof of the mouth, and it is very doubtful whether they are borne by the vomer. It seems then that the term "vomerine" teeth, designating teeth borne by a definite bone, the vomer, as used for other fishes, does not always apply to eels. Therefore, for practical taxonomic purpose, the non-commital term palatal teeth is here used, simply signifying the median series of teeth on the palate. This term is adequate and is generally useful in describing the dentition in the species of this order.

The three series of teeth are confluent anteriorly or more or less separated, depending on the genus or species and to some extent also on intraspecific individual variability.

The number of rows of teeth in any series is sometimes used as a specific or even generic character, and it often is a usable taxonomic character. However, in using this character, it should also be borne in mind that in many species the number of rows increases with growth. This change with growth has been noted for several of the species included in this account, as for instance in *Ophichthus gomesii.*

In listing the specimens examined under each species, M.C.Z. refers to the Museum of Comparative Zoology; B.O.C. stands for Bingham Oceanographic Collection; while numbers without letters are those in the catalog of the U. S. National Museum.

KEY TO THE FAMILIES OF APODAL FISHES BASED ON THE SPECIES FROM THE NORTHERN PART OF THE GULF

a. Posterior nostril placed above upper lip, on a horizontal through lower margin of eye or higher. Without or with a slightly raised rim. Caudal fin present, continuous with dorsal and anal, posterior end of fish thus surrounded by a continuous fin fold.

b. Gill opening larger than eye. Pectorals present.

c. Scales present. Lower jaw somewhat projecting.. *ANGUILLIDAE* (p. 435).

cc. Scales absent. Upper jaw slightly or notably projecting ... ... *CONGRIDAE* (p. 436).

bb. Gill opening subequal to or smaller than eye.
Pectorals absent ....*MURAENIDAE* (p. 458).

aa. Posterior nostril placed on upper lip or in that position when lip undifferentiated, with a wide flaring margin (except in *Verma*, an ophichthid genus lacking all fins, nostril placed just above lip and without raised edge).

d. Caudal fin present, continuous with dorsal and anal.. *ECHELIDAE* (p. 463).
dd. Caudal fin absent, posterior end of fish without fin fold, dorsal and anal ending at some distance from posterior end (absent altogether in *Verma*) *OPHICHTHIDAE* (p. 465).

FAMILY ANGUILLIDAE

This family is represented by only one species in the western Atlantic, the common fresh water eel.

ANGUILLA Shaw

Anguilla Shaw, General Zoology, vol. 4, pt. 1, p. 15, 1803 (genotype *Muraena anguilla* Linnaeus by tautonymy)

ANGUILLA ROSTRATA (LeSueur)

Muraena rostrata LeSueur, Jour. Acad. Nat. Sci. Philadelphia 1(5): 81, October 1817 (Cayuga and Geneva Lakes, New York)
Muraena bostoniensis LeSueur, ibid. (Boston market, Massachusetts)
Muraena serpentina LeSueur, ibid. (Newport, Rhode Island)
Muraena argentea LeSueur, 1. c., p. 82 (Boston Bay)
Muraena macrocephala LeSueur, 1. c., p. 82 (Saratoga, New York)
Anguilla chrisypa Rafinesque, Amer. Monthly Mag. & Critic. Rev. 2(2):120, December 1817 (Lake George, Hudson River, Lake Champlain; refers to LeSueur's paper, showing that it was published earlier)
Anguilla blephura Rafinesque, ibid. (Long Island)
Anguilla laticanda (an evident lapsus or printer's error for laticauda) Rafinesque, 1. c., vol. 3, no. 6, p. 447, 1818 ("Ohio Eel")
Anguilla bostoniensis Gunther (in part), Cat. Fish. British Mus. 8: 31, 1870 (Boston; account based in part on specimens from China and Japan and includes more than one species)—Jordan, Manual of the Vertebrate Animals of the Northeastern United States, p. 56, 1929 (S. Greenland to Brazil)
Anguilla chrysypa Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 668, 1891 (Maine to Mexico and West Indies; synonymy)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47(1): 348, 1896 (Maine to Mexico; West Indies; synonymy)
Anguilla rostrata Bean, Science 29: 871, 1909 (states that *rostrata* has priority over *chrisypa*)—Jordan, Copeia 1917: 86 (*rostrata* has priority over *chrisypa*)—Schmidt, Rep. Smithsonian Inst. 1924: 279-314, 1925 (life history)—Ege, Dana Report 16: 89 and passim, 1939 (literature on distribution summarized on p. 149; Labrador to Guiana, including the West Indies; synonymy)

Scales cycloid, small, elongate, moderately imbricated with a peculiar and characteristic arrangement in irregular groups, longitudinal axis of scales in any one group running either downward and forward, or downward and backward, scales in one group running at right angles to those in an adjacent group. Compressed, rather deep. Tail moderately tapering, longer than body. Eye moderate, 2.0-2.8 in snout (in 4 specimens 530-624 mm). Mouth and jaws of medium extent; lower jaw 3.0-3.1 in head; angle of mouth approximately under posterior margin of eye. Snout notably depressed, broad, blunt, 4.4-4.9 in head; lower jaw somewhat projecting. Lips forming a well developed fold, separated by a rather deep groove. Posterior nostril without a raised rim, placed near eye, on a horizontal through its upper margin or a little below; anterior nostril ending in a short tubule, placed near anterior lateral corner of snout. Tongue free, well developed. Gill opening transverse, lateral, near to and in front of pectoral base, its upper angle at some distance below upper pectoral angle, its lower angle below pectoral base. Dorsal origin much nearer vent than gill opening. Pectoral, dorsal, anal and caudal well developed, the latter three fins continuous. Teeth of medium size, subequal, in tapering bands in jaws and on palate; bands in jaws of moderate width; palatal band broad in front, becoming abruptly narrower and tapering to a point opposite eye; premaxillary teeth in a patch continuous with palatal band, except for a slight, somewhat hourglass-like constriction between the two areas of teeth; teeth in jaw moderately or slightly separated from palatal and premaxillary teeth. Color olivaceous, brownish or grayish, almost uniform except lighter on ventral aspect; without spots or other markings.

Measurements of 4 specimens 530-624 mm, and 2 specimens 188-271 mm, all six from the Gulf Coast of the United States: body 43-46 (40-43), trunk 29-32 (27-30), tail 54-58 (57-60), antedorsal 34-36 (31-33), head 13.0-13.5 (12.5-13.5), upper jaw 3.9-4.3 (3.2-3.7), lower jaw 4.2-4.6 (3.6-4.1), snout 2.7-3.1 (2.4-2.7), eye 1.1-1.4 (1.5-1.6), depth 6.4-7.9 (6.3), pectoral 4.7-5.7 (3.7-3.9). In the two smaller specimens eye 1.5-1.9 in snout, lower jaw 3.3-3.5 in head, snout 4.9-5.1 in head. (These three ratios of the 4 larger specimens given above in diagnosis.)

Two specimens from the coast of Massachusetts and one from Cuba, comparable in size to the preceding 4 larger Gulf specimens, average the jaws, snout and pectoral shorter and the eye larger, but the divergence is not pronounced.

Gulf Coast specimens of this species were examined from the following localities: mouth of the Rio Grande, Fort Clark, Corpus Christi, Copano Bay, New Braunfels, San Marcos Springs, Colorado River at Austin and Galveston Bay, Texas; Grand Isle, Baton Rouge and New Orleans, Louisiana; Vicksburg and Jackson, Mississippi; Pensacola and Apalachicola, Florida. The largest specimen is 805 mm from Fort Clark.

This species is distinguished from all known Gulf eels by the presence of scales which are arranged in a characteristic manner. It is often necessary to scrape off the mucous in order to see the scales. The snout is notably broad and flat and the lower jaw somewhat projecting. The dorsal origin is much nearer to the vent than the gill opening. The teeth are rather small and in bands. It differs from *Conger caudilimbatus* and most other eels here treated by the notably backward insertion of the dorsal fin.

NOMENCLATURE*—The scientific name of the common American fresh water eel has been changed repeatedly and its usage is still marked by instability. The main points in the nomenclatorial history of the species are, therefore, here briefly reviewed.

At the turn of the century, *chrisypa,* one of two names proposed by Rafinesque in 1817 for this species, or its amended form *chrysypa,* was generally used by American authors. Bean (1909) and Jordan (1917) concluded that the five names proposed by LeSueur in the same year for this species, have date priority over Rafinesque's names, and LeSueur's name *rostrata* which has line or page priority over his other four names, came into general usage. In 1929, Jordan pointed out that Gunther (1870) who presumably was the first reviser, chose the name *bostoniensis,* and since then most American authors, but not all, used the latter name for the species. Ege (1939) who published the most comprehensive account of the genus as a whole, and the best one so far, uses the name *rostrata.*

Two names, *bostoniensis* and *rostrata,* are then currently in use for this same species. The choice between these two names depends on a decision as to who was the first reviser. The pertinence of accepting Gunther as the first reviser is open to question. First, Gunther's work is not a revision in the true sense of the word. It is rather a compilation reinforced by original observations on a limited amount of specimens. Second, Gunther did not separate his specimens properly, and his account under the name *bostoniensis* is based on a mixture of two distinct species. Third, Gunther was uncertain in regard to the status of all five names proposed by LeSueur for this same species. While he places *rostrata, argentea* and *macrocephala* in the synonymy of his *bostoniensis,* he lists *serpentina* among the doubtful species. On the other hand, Ege's work on the genus *Anguilla* is so comprehensive and of such quality as to truly deserve the title revision. It seems to me that the extent and quality of an author's work should be considered in deciding the question as to who was the first reviser. In case of doubt, especially, this latter factor should be considered. Therefore, I accept Ege as the first reviser and the name *rostrata,* as used by that author is here employed for the common American fresh water eel.

FAMILY CONGRIDAE

Scales absent. Moderately stout to slender. Tail moderately to much longer than body, except a little shorter in *Neoconger.* Mouth rather small to large; upper jaw slightly to notably projecting beyond lower, premaxillary teeth well exposed or covered with the mouth closed. Lips separated from or continuous with surface of skin. Posterior nostril placed in front of middle or lower half of eye, close to eye or

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*This paper was written and submitted for publication before the revised international rules of zoological nomenclature appeared in print, adopting the principle of page or line priority, in place of the rule of the first reviser. According to the revised rules, the species name of the common American fresh water eel should be **rostrata**, as it is here used.

at a moderate distance away, with or without a slightly raised rim. Anterior nostril in a short, broad tubule, except in *Neoconger,* placed near end of snout or at a moderate distance behind, about on a horizontal through posterior nostril, except in *Congrina.* Tongue free or adnate, depending on the genus. Gill opening moderate to large, lateral or placed very low, that is, altogether entering ventral as well as lateral aspect, transverse or horizontal. Dorsal, anal, pectoral and caudal fins present, vertical fins continuous around posterior extremity of fish; caudal short or rather long (for an eel). Dentition differing widely with the genus; canines on palate present or absent; jaw, as well as premaxillary teeth, subequal or differing moderately within each series, without large canine teeth, except in *Hoplunnis.*

Of the species of eels here treated, those belonging to the family Congridae differ from species of other families in external characters as follows. They differ from the Echelidae and Ophichthidae in having the posterior nostril buccal, instead of labial, and they differ further from the latter in having a caudal fin fold. They differ from the Anguillidae in lacking scales, and from the Muraenidae in having a pectoral fin and larger gill opening.

KEY TO THE GENERA AND SPECIES OF THE FAMILY CONGRIDAE

a. Palatal teeth small, in an elongate, rounded, or somewhat tapering patch, or in a single row, without canines. Lower jaw about as wide as upper.

b. Dorsal origin over pectoral or gill opening. Tail longer than body, 53-72. Tongue free. Upper and lower lip differentiated. Palatal teeth not extending to opposite eye. Eye large, 2.4-4.1. Pectoral medium to rather long, 4.2-7.4.

c. Snout only a little projecting beyond lower jaw. Premaxillary teeth partly exposed and beginning nearly at end of snout. Upper lip in a well developed, upturned fold, not covered by a fold of skin on cheek. Caudal short, 1.1-1.2.

d. Dorsal beginning approximately over middle of pectoral. Teeth in main outer row somewhat incisor like, closely approximated.. *Conger caudilimbatus* (p. 439).

dd. Dorsal beginning approximately over pectoral base. Teeth in main outer row pointed, moderately spaced.. *Congermuraena impressa* (p. 441).

cc. Snout notably projecting beyond lower jaw, rather tapering. Premaxillary teeth nearly all exposed, beginning considerably behind tip of snout. Upper lip moderate, not forming an upturned fold, covered by a broad, thick fold in the loose skin of the cheek. Caudal 2.2-7.7..................*Congrina* (p. 442).

e. Tail 61-71, depth 4.5-6.8, trunk 16.5-20.5. Teeth in palatal patch subequal or the posterior teeth slightly larger, the patch usually oblong, sometimes nearly wedge-shaped.

f. Body 39, antedorsal 19, head 19.5 and caudal 7.7 in a specimen 128 mm. ....*Congrina macrosoma* (p. 443).

ff. Body 29-35, antedorsal 12.5-14.0, head 13.5-18.0 and caudal 2.2-5.2 in 6 specimens 75-308 mm; same measurements 31-37, 14.0-16.5, 14-17 and 3.4-6.0 in 6 specimens 340-464 mm...*Congrina flava* (p. 444).

ee. Tail 73, depth 3.5-3.6, trunk 13.5-14.5, antedorsal 13.0-13.5, head 12.5-13.0 and caudal 2.2-2.5 in 2 specimens 135-202 mm. Teeth in palatal patch unequal, the posterior teeth nearly caninoid, the patch wedge-shaped. *Congrina gracilor* (p. 445).

bb. Dorsal origin over, or a short distance in front of vent. Tail a little shorter than body, 47-49. Tongue virtually adnate. Upper lip not, and lower lip slightly, differentiated. Palatal teeth extending to opposite eye. Eye small, 0.7-0.9. Pectoral short, 1.8-2.7. Caudal 2.6-3.3. Snout tapering, short, extending moderately beyond lower jaw .... *Neoconger mucronatus* (p. 446).

aa. A median row of widely spaced canines on palate. Lower jaw narrower than upper. Tongue adnate.

g. Jaws somewhat beloniform, rather slender and bony. Upper jaw not forming a trough for reception of lower jaw. Palatal canines in median row 6-8. A very long canine on each side of lower jaw, other teeth unequal. Premaxillary teeth canine, exposed. Body notably slender and tapering, depth 2.0-2.7. Dorsal origin at a short distance before gill opening. Tail 74-77........ *Hoplunnis* (p. 447).

h. Teeth in jaws in three rows. Caudal probably short. Tail notably tapering at posterior end. Row of large teeth on palate flanked by small teeth.

i. Anterior teeth in inner row of lower jaw notably larger than outer teeth, widely spaced. A row of small teeth in upper jaw at angle of mouth between outer band of teeth and midline of palate. Large palatal teeth 8. Antedorsal 10; head 11.5.. *Hoplunnis tenuis* (p. 448).

ii. Anterior teeth in inner row of lower jaw not as large in comparison with outer teeth, rather closely approximated. No row of teeth in upper jaw behind outer band of teeth. Large palatal teeth 6. Antedorsal 7.5; head 9........ *Hoplunnis diomedianus* (p. 449).

hh. Teeth in jaws in two rows. Caudal notably long (for an eel). Tail moderately tapering. Large palatal teeth not flanked by small teeth. No row of teeth in upper jaw behind outer band of teeth. Large palatal teeth 6........ *Hoplunnis macrurus* (p. 450).

gg. Jaws anguilliform, covered with thick skin, the upper jaws having appearance of eel-like width. Lower jaw fitting into trough formed by upper jaw and soft parts surrounding it. Palatal canines in median row 3-4, without small teeth beside them. Teeth in lower jaw subequal, without a long canine. Premaxillary teeth moderate, not exposed, or absent. Body moderately deep and tapering, depth 5.6-5.7.

j. Vent at a considerable distance behind pectoral, tail 72. Dorsal origin at a short distance behind end of pectoral. Band of teeth in upper jaw extending nearly its entire length; dentition of lower jaw similar to that of upper. No premaxillary teeth . *Dysommina rugosa* (p. 450).

jj. Vent notably far forward, under end of pectoral; tail 81-83. Dorsal origin a little in front of pectoral base. Band of teeth in upper jaw short, ending before angle of mouth; dentition of lower jaw dissimilar to that of upper, teeth larger, in a single row, well spaced. Two premaxillary teeth .... *Dysomma aphododera* (p. 452).

CONGER Cuvier

les Congres Cuvier, Regne Animal, ed. 1, t. 2, p. 231, 1817 (French name only; two species included, *Muraena conger* Linnaeus and *M. myrus* L.; no genotype indicated).

Conger Oken, Isis, p. 1183, 1817 (Cuvier's French name latinized)—Internat. Comm. Zool. Nomencl., Opinion 93, p. 5, 1926 (The name *Conger* ascribed to Cuvier, 1817 and *Muraena conger* Linnaeus designated as its genotype by plenary power.)

Ariosoma Swainson, Natural History of Fishes Amphibians and Reptiles, vol. 1, p. 220, 1838 (genotype *Ophisoma obtusa* Swainson by subsequent designation)

Ariosoma Swainson, 1. c., vol. 2, p. 196, 1839

Ophisoma Swainson, 1. c., vol. 2, p. 334, 1839 (evidently a substitute name for *Ariosoma*)

Ophisoma Swain, Pr. Ac. Nat. Sci. Philadelphia 1882: 283, 1883 (*Ophisoma obtusa* Swainson designated as genotype).

Conger is near in relationship to *Congermuraena* and the differences between them are discussed below under the account of the latter. The generic characters are included below in the description of the single species here treated.

Of late years the name *Ariosoma* has been used by American authors for that genus which was formerly known as *Congermuraena.* This unfortunate nomenclatorial change stems from Jordan's "Genera of Fishes" (1919, pp. 193 and 272). However, *Ariosoma* is apparently a synonym of *Conger,* and is here added to the synonymy of this genus, as a reexamination of the pertinent literature shows that Jordan's conclusion is not tenable.

Ariosoma was first introduced by Swainson (1938, p. 220) in connection with a general discussion of the biology and anatomy of fishes, as a new genus with a brief diagnosis—which by the way applies to several congrid genera, but this is beside the point—and without mentioning any species. Later, the same author (1839, p. 196) in connection with a summary arrangement of the genera, includes *Ariosoma,* with virtually the same diagnosis and again without mentioning any species. Further on in the same volume (p. 334), where he gives a somewhat more elaborate account of most genera, *Ariosoma* is left out, but he includes a genus *Ophisoma* for which he gives virtually the same diagnosis as he previously gave for *Ariosoma.* He also places *Ophisoma* in the same position with respect to the other genera, that was previously occupied by *Ariosoma.* There is hardly any question that Swainson introduced *Ophisoma* as a substitute for *Ariosoma,* although he does not so state. These two names, therefore, must go together. Under *Ophisoma* he mentions two species, *obtusa* and *acuta,* which he describes further on in the same volume (pp. 395-396), but no genotype is designated.

Bleeker (1864, p. 20) recognizes *Ophisoma* as a valid genus, the summary account of which he heads as follows: "*Ophisoma* Swns.=*Ariosoma* Swns.=*Congermuraena* Kp." Bleeker also states: "Spec. typ. *Ophisoma balearicum* Blkr. = *Ophisoma acuta* Swns.?" Evidently what Bleeker did was to designate *balearicum* as the genotype of *Ophisoma;* but this is unacceptable because *balearicum* was not one of the originally contained species. Bleeker also indicated that the *O. acuta* of Swainson might be the same as *balearicum,* but he questions it, and where an author uses a query in indicating a genotype it cannot be accepted as a valid genotype designation. Therefore, Jordan is in error in concluding that Bleeker designated a genotype for *Ophisoma* and hence by implication also for *Ariosoma* for which *Ophisoma* is a substitute.

Swain (1883) designates *obtusa* as the genotype of *Ophisoma,* which also must be taken as the genotype of *Ariosoma.* These two generic names thus presumably become synonyms of *Conger,* as *O. obtusa* Swainson is now thought to have been based on a specimen of the common *Conger conger,* although it does not appear that a definite study has ever been made to settle this question.

CONGER CAUDILIMBATUS (Poey)

Echelus caudilimbatus Poey, Rep. Fis. Nat. Cuba 2:249, pl. 2, fig. 8, 1867 (Cuba)

Ophiosoma caudilimbatus Poey, Syn. Pisc. Cub., p. 424, 1868 (Cuba)

Conger caudilimbatus Poey, Enum. Pisc. Cub., p. 152, 1876 (Cuba)

Conger caudicula Bean, Proc. U. S. Nat. Mus. 5: 435, 1882 (Pensacola)

Leptocephalus caudilimbatus Jordan and Davis, Rep.U. S. Comm. Fish. 1888: 666, 1891 (Tropical Atlantic, Pensacola to Madeira)—Jordan and Evermann, Bull. U. S. Nat. Mus. 46(1): 355, pl. 57, fig. 149, 1896 (Tropical parts of Atlantic; Pensacola to Cuba and Madeira)

Moderately compressed to subterete, rather deep. Tail moderately tapering, moderately longer than body. Eye large, 1.0-1.2 in snout. Jaws and mouth medium large; lower jaw 2.7-3.1 in head; angle of mouth under space between posterior margin of pupil and eye; premaxillary teeth partly exposed with the mouth closed. Snout 4-5 in head, moderately tapering, extending a little beyond lower jaw; premaxillary teeth extending nearly to its anterior margin. Upper lip well separated, in form of notably well developed, upward-directed fold; lower lip a well developed fold. Posterior nostril rather large, placed at a moderate distance in front of eye and on a horizontal through its middle or a little below, near edge of broad upturned lip, its margin slightly raised; anterior nostril in a moderate tubule, placed nearly on lateral profile at a short distance from end of snout. A pore in front of and over anterior nostril; one behind anterior nostril at beginning of lip fold, one over and a little in front of posterior nostril. Tongue free, well developed. Gill slit mainly lateral, transversely curved: of medium extent, its width about equalling distance between the two fellows. Dorsal origin over middle of pectoral, varying a little both ways; dorsal, anal and pectoral fins rather well developed; caudal comparatively short. Teeth in outer, in the main, row in each jaw closely approximated. anterior teeth tapering, pointed, posterior teeth, for greater extent of row, compressed, almost incisor like but their distal edge more or less obliquely truncate, forming an almost continuous cutting edge; inner teeth in jaws mainly in one row, well separated from outer row, somewhat pointed but short and stout, almost molar-like, the row ending for some distance before angle of mouth, smaller inner teeth for a short distance anterior to stout teeth in two rows in upper jaw, in three rows in lower jaw; palatal patch of teeth wedge-shaped, not extending far backward, greater part of patch consisting of two rows of short, stout, almost molar-like teeth, converging posteriorly to one tooth on midline, front part of patch, in a small area, having small, slender, pointed teeth in 4 irregular rows; premaxillary teeth in 4 irregular, lengthwise rows, the teeth at the periphery of the patch larger than all other teeth, caninoid; jaw, palatal and premaxillary teeth fairly separated. Yellowish without distinctive markings, vertical fins edged posteriorly with blackish or dusky.

In a small specimen from Key West, 128 mm (131526), the teeth are fewer, the palatal patch ends in 2 stout teeth on midline, one behind the other, and the dorsal and anal are edged with whitish. I assume that these are juvenile characters.

Measurements of 5 specimens 218-334 mm and one specimen 128 mm: body 43-46 (41), trunk 26-29 (24), tail 54-57 (59), antedorsal 19-21 (21), head 16.0-17.5 (17.5), upper jaw 6.0-7.4 (6.4), lower jaw 5.5-6.5 (5.7), snout 3.5-4.4 (4.1), eye 3.4-4.1 (3.7), depth 4.9-6.3 (3.9), pectoral 4.8-6.5 (5.4), caudal 0.5-1.1 (1.2).

Specimens examined from or off the following localities: Dauphin Island, Alabama (B.O.C. 2937, collected by the Atlantis); Pensacola (30709, the type of *caudicula;* 33000) and Key West (131526), Florida; Cuba (M.C.Z. 9324, two cotypes of *caudilimbatus*). The measurements of these six specimens given above. One specimen was taken by the Atlantis at 20 fathoms. No depth records are available for the others.

This species is distinguishable from the Atlantic *Conger oceanicus* by the more forward insertion of the dorsal, and by averaging a relatively longer body and shorter tail. The species of *Congermuraena* have the dorsal origin still farther forward, over the pectoral base.

CONGERMURAENA Kaup

Congermuraena Kaup, Cat. Apodal Fish Brit. Mus., p. 108, 1856 (genotype *Muraena balearica* De la Roche by subsequent designation)

Congromuraena Gunther, Cat. Fish. Brit. Mus. 8: 40, 1870 (evidently an emendation of *Congermuraena*)

Congermuraena Jordan and Davis, Rep. U. S. Comm. Fish 1888: 659, 1891 (*Congermuraena* placed in synonymy of *Ophisoma* Swainson, but the genotype of the former designated as *balearica*)

Congrellus Ogilby, Proc. Linn. Soc. N. S. Wales 23: 286, 1898 (genotype *Muraena balearica* De la Roche by original designation)

The separation of *Congermuraena* as a genus distinct from *Conger,* rests on tenuous grounds. The two genera are chiefly separated by the position of the dorsal origin and the character of the dentition. However, the dorsal origin in *Conger caudilimbatus* is intermediate between that of *Conger conger* and *Congermuraena impressa.* Also, the inner teeth in the jaws of *C. impressa* are similar in form and arrangement to the teeth in the outer row of *C. conger* or *C. caudilimbatus.*

In recent years the generic name *Congermuraena* was replaced by *Ariosoma* by American authors. However, *Ariosoma* is apparently a synonym of *Conger* as discussed above under that genus.

CONGERMURAENA IMPRESSA (Poey)

Conger impressus Poey, Mem. Hist. Nat. Cuba 2:318, 1860 (Cuba)
Ophisoma impressus Poey, Rep. Fis. Nat. Cuba 2: 248, pl. 3, fig. 2, 1867 (Cuba)
Ophiosoma impressus Poey, Syn. Pisc. Cub., p. 424, 1868 (Cuba)
Congromuraena impressa Poey, Enum. Pisc. Cub., p. 152, 1876 (Cuba)
Ariosoma minor Howell Rivero, Mem. Soc. Cub. Hist. Nat. 8: 339, 1935 (Havana, Cuba)

Compressed to subterete, depth moderate. Tail moderately tapering for a moderate or short distance, moderately longer than body. Eye large, 1.1-1.3 in snout. Mouth and jaws of medium extent; lower jaw 3.4-4.1 in head; angle of mouth approximately under anterior margin of pupil; premaxillary teeth a little or slightly exposed with the mouth closed. Snout 3.8-4.7 in head, blunt or bluntly pointed, extending slightly or moderately beyond lower jaw, the anterior premaxillary teeth placed nearly at its tip. Upper lip moderately or well developed and separated by a groove, with an upwardly directed fold; skin on cheek moderately loose not forming a fold to cover the lip; lower lip separated forming a notably well developed fold. Posterior nostril large, without a raised edge, placed at a moderate distance in front of eye and a little below a horizontal through its middle; anterior nostril with a broad, low tubule, placed at lateral outline, a short distance from end of snout, at beginning of upper lip fold. A rather large pore directly behind anterior nostril, and a small one near lip at a short distance from eye; a medium sized pore at some distance over anterior and posterior nostril. Tongue free. Gill opening transversely curved, lateral, placed rather low, near ventral profile, of medium extent, the space between the two fellows wider than the opening. Dorsal origin over gill opening; dorsal, anal and pectoral rather well developed; caudal short. Teeth small, subequal, no canines; in bands of moderate width in jaws, 4 irregular rows anteriorly tapering to 2 rows posteriorly; palatal patch elongate, wedge-shaped, 4 irregular rows anteriorly tapering to one row posteriorly for 1-3 teeth, ending opposite posterior nostril; premaxillary patch roughly in 6 rows on a transverse axis; premaxillary, palatal and jaw teeth continuous, or nearly so, as a consequence, entire dentition of upper jaw forming a broad area in front and continued backward in three tapering bands; posterior teeth in innermost row in jaws rather closely approximated, blunt, somewhat compressed; posterior palatal teeth stout and rather blunt; other teeth slender, pointed; the preceding description of dentition based on specimens 211-235 mm; in a 272 mm specimen bands of teeth somewhat wider anteriorly and posterior single row of palatal teeth continued to a vertical midway between posterior nostril and eye; a specimen 180 mm differing in that the jaws having a single row for a short distance near angle of mouth, a continuation of the innermost row. Almost uniformly light brownish or yellowish, under side of belly somewhat lighter; no distinctive markings; posterior part of vertical fins edged with dusky or black.

Measurement of 4 specimens, 211-272 mm: body 45-48, trunk 29-31, tail 52-55, antedorsal 16.5-17.5, head 16.0-17.5, upper jaw 4.6-5.6, lower jaw 4-5, snout 3.4-4.6, eye 3.1-3.5, depth 4.4-6.9, pectoral 5.0-6.8, caudal 0.8-1.2.

Specimens examined from or off the following localities: Cape Hatteras, North Carolina (155002, collected by the Pelican); St. Augustine, Florida (155003, Pelican); Dauphin Island, Alabama (B.O.C. 2938, collected by the Atlantis); Cuba (37568, sent in by Poey and now labeled *Congermuraena impressa;* M.C.Z. 33452, holotype of *Ariosoma minor*). Total examined 5 specimens 180-272 mm. Depth records for the first 3 listed specimens range 11-20 fathoms.

The types of (*Ariosoma*) *Congermuraena selenops* (Reid, 1934, p. 4) have the gill openings larger and placed lower than *impressa* and the two species also differ in some proportional measurements as shown below. Norman (1925, p. 314) gives some measurements of specimens from Brazil, which he identified as belonging to *Congermuraena opisthophthalmus* (Ranzani) and Mediterranean specimens of *C. balearica* (De la Roche). Norman's measurements of 5 specimens of *balearica* 275-364 mm and 7 specimens of *opisthophthalmus* 175-280 mm, reduced to proportional figures and compared with 2 types of *selenops* 342-474 mm and 4 of *impressa* 211-272 mm, are as follows, the four ranges under each measurement are in order *opisthophthalmus, selenops, impressa* and *balearica*: body 42-44, 43, 45-48, 47-48; trunk 26-28, 24-26, 29-31, 31-34; tail 57-58, 57-58, 52-55, 52-53; head 15-16.5, 16.5-18.5, 16.0-17.5, 14-15.5. Therefore, *impressa* has a longer body and trunk and shorter tail than *opisthophthalmus* and *selenops,* while *balearica* diverges on the average still farther from the latter two species in the same measurements. Also, *selenops* and *opisthophthalmus* about agree in the body and tail measurements and differ in the head and trunk measurements. Nearly the same differences and similarities are noted in comparing *impressa* with *balearica.* The differences, in general, are not pronounced and some of these names have been synonymized by authors. It is evident that the 4 species, if indeed all of them are distinct in reality, need to be further compared directly by the study of adequate samples.

Norman's *Congromuraena guppyi* from Tobago Island described in the paper cited, is said to have: "Teeth bluntly conical or granular . . ." and apparently does not belong to the genus *Congermuraena.*

CONGRINA Jordan and Hubbs

Congrina Jordan and Hubbs, Mem. Carnegie Mus. Pittsburgh 10: 196, 1925 (genotype *Congermuraena aequorea* Gilbert and Cramer by original designation)

Congrina Reid, Smithsonian Misc. Coll. 91(15): 7, 1934 (discusses relationship of *Congrina*, presents a key comparing it with some of its near relatives, and names the species belonging to it)

Compressed, rather deep or depth moderate. Tail notably or excessively tapering, considerably longer than body. Eye rather large, 1.1-1.7 in snout. Jaws and mouth of medium extent; lower jaw 3.1-3.8 in head; angle of mouth under space between posterior margin of pupil and eye; premaxillary patch of teeth exposed with the mouth closed. Snout 3.4-4.3 in head, moderately tapering, extending notably beyond lower jaw and premaxillary teeth. Upper lip moderate, not forming an upwardly directed fold, separated by a moderate groove, closely apposed to edge of jaw; skin on cheek and snout notably loose, forming a broad, thick fold overhanging and covering the moderate lip; processes from buccal ossicle (see below) impinging on loose skin of fold, and may be seen or felt without dissection. Lower lip differentiated, forming a well developed fold. Posterior nostril large, near eye and on a horizontal through its middle, its edge slightly or moderately raised; anterior nostril placed on ventral aspect of snout or nearly so, opposite anterior part of premaxillary patch of teeth, its edge well raised. Two pores, in a lengthwise row close to midline on ventral aspect of snout, the posterior one near premaxillary teeth, the two fellow rows diverging forward; a very large pore, about as large as nostril, on dorsal aspect of snout, near its lateral profile and not far from its tip; a series of three pores along margin of fold on cheek. Tongue free, well developed. Gill opening transversely curved, lateral, of medium extent, the space between the two fellows wider than opening. Dorsal origin over gill opening; dorsal, anal, pectoral and caudal fins rather well developed. Teeth rather short, pointed, differing moderately in size in different series; teeth in jaws in bands tapering backward; palatal teeth somewhat stouter than others, in a rounded or somewhat elongate or subtriangular patch, not extending to a vertical through posterior nostril, moderate canines or caninoids in palatal patch present or absent, depending on the species; premaxillary teeth somewhat longer than others (excluding the canines when present), in a transversely oblong patch somewhat rounded in front; palatal, premaxillary and jaw teeth slightly or hardly separated from one another. Almost uniformly yellowish, under side of belly somewhat lighter, sometimes with a purplish tinge; no distinctive markings; posterior part of vertical fins usually edged with black.

The above is an outline of the characters common to the four western Atlantic species examined. Their differences are outlined under the accounts of the species.

Congrina differs chiefly from *Congermuraena* and *Conger* as follows. In *Congrina* the upper lip is narrow and closely apposed to the edge of the jaw. The skin on the head is excessively loose, and forms a fold at the lower part of the cheek, which covers the lip, at least in preserved specimens. The snout well overhangs the underslung mouth, and its ventral aspect, from the premaxillary teeth to its tip is of considerable extent. The caudal is rather long and pointed. The pores on the snout and cheek are excessively enlarged and numerous. In *Congermuraena* and *Conger* the upper lip is well developed and forms an upwardly directed fold. The skin on the head is moderately loose and does not form a fold, leaving the upper lip exposed. The snout is obtuse and hardly extends beyond the premaxillary teeth. The caudal is short and rounded. The pores are moderate in size and number. The above differences have been determined mainly for the species here treated and for the genotype, *aequorea* of Gilbert and Cramer. Whether *Congrina* can be separated on the basis of these characters when all the relevant species are considered remains to be seen.

Reid (above citation) separates *Congrina* from *Congermuraena* (which he calls *Ariosoma*) to a large extent by the structure of the buccal ossicle. I partly dissected one specimen each of *Conger oceanicus* (Mitchill), *Congermuraena selenops* (Reid) and *Congrina flava* (Goode and Bean), as follows. I made a longitudinal slit in the skin of the lower part of the cheek, pulled the skin loose and deflected it both ways, and cleaned away part of the connective tissue to partly expose the buccal ossicle. While this, of course, does not constitute a thorough study of this structure, I may in a preliminary way describe it as follows.

In all three species, the buccal ossicle is trough shaped, with the trough turned on the side, and having its bottom entad and its open side ectad. From the upper and lower margin of the lengthwise lips of the trough two or three bony processes extend downward and upward, respectively. In *C. oceanicus* and *C. selenops* the processes are rather broad and the opposite fellows from above and below are connected by a strong ligament. They are not visible on the outside in undissected specimens. In *Congrina flava* the processes are longer and narrower and rather loosely connected. They impinge on the skin and may be appreciated on the outside or felt by pressing a scalpel or needle against them. Evidently, the difference in this structure between the three species is, in general, not fundamental. In none of the three species do the bony processes enter the lip. Reid states: "bones of facial canal sending pointed processes to edge of lip." Evidently, by "lip" he meant the lengthwise fold of skin on the lower part of the cheek, which, however, is separated from the narrow lip by a lengthwise groove.

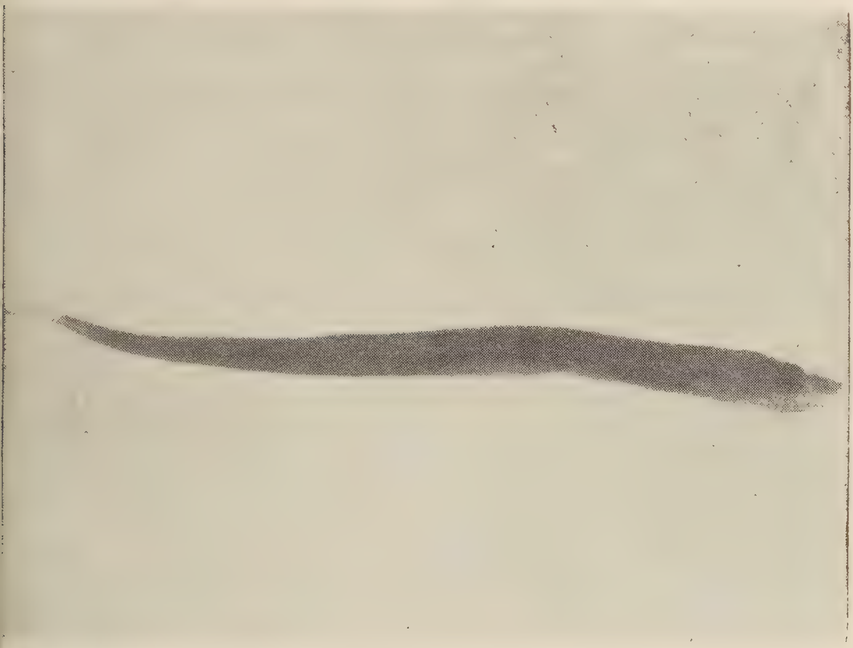

FIGURE 1.—*Congrina macrosoma;* from the holotype; Bingham Oceanographic Collection 3939; 128 mm; off Isle Derniere, Louisiana.

CONGRINA MACROSOMA, new species

Moderately deep, the tail moderately tapering. Palatal patch of teeth transversely oblong, its posterior teeth only slightly larger than anterior teeth; in a specimen 128 mm irregular rows of teeth roughly as follows: anterior teeth in upper jaw 4, in lower jaw 5; across widest part of palatal patch 6; premaxillary patch, across 7, along longitudinal axis 5.

Measurements of holotype: body 39, trunk 19, tail 61, antedorsal 19.0, head 19.5, upper jaw 7.4, lower jaw 5.5, snout 4.8, eye 4.1, depth 6.4, pectoral 6.8, caudal 7.7.

HOLOTYPE—B.O.C. 3939; Atlantis Station 2840; lat. 28° 19' N, long. 90° 59' W, off Isle Derniere, Louisiana; 31 fathoms; March 25, 1937; 128 mm.

This species has a notably shorter tail and concomittantly a longer body than its three western Atlantic congeners, the difference being of such degree as to make it fairly certain that the one specimen examined represents a distinct species. On the assumption that the holotype is a small specimen of a larger species, the difference is probably greater than the single specimen indicates. In the species of *Congrina*, as well as in other eels, the tail also differs intraspecifically with growth, being relatively longer in the smaller specimens; while the small holotype has the tail shorter than larger specimens of the other three species. This species also has the antedorsal, head, jaws and caudal longer than in the other three species. The dentition is about as in *flava* and it is probably most nearly related to that species.

CONGRINA FLAVA (Goode and Bean)

Congermuraena flava Goode and Bean, Oceanic Ichthy., p. 138, pl. 42, fig. 159, 1895 (off Trinidad, Grenada and Florida, lectotype indicated below)—Jordan and Evermann, Bull. U. S. Nat. Mus. 46(1): 357, 1896 (after Goode and Bean)

Congrellus flavus Jordan and Everman, ibid., pt. 4, pl. 58, fig. 150, 1900 (generic name changed in labeling figure)

Congrina flava Reid, Smithsonian Misc. Coll. 91(15): 7, 1934 (placed in *Congrina*)

Moderately deep, the tail moderately tapering in comparison. Palatal patch of teeth usually transversely oblong in the smaller specimens, longitudinally oblong in large fish, sometimes nearly wedge-shaped (in a small specimen); the teeth in the patch subequal or the posterior teeth slightly larger. Bands and patches of teeth increasing in width and size with growth; not arranged in regular rows, but very roughly, in terms of irregular rows, in 2 specimens 183 and 464 mm, respectively, as follows: anterior part of upper jaw 4 and 7 rows, of lower jaw in 5 and 8 rows; widest part across palatal patch 6 and 8 rows; premaxillary patch, across 7 and 10 rows, along longitudinal axis 6 and 9 rows.

Measurements of 11 Gulf of Mexico specimens divided into 3 size groups 340-464 (6), 183-308 (4), 75 (1); the following measurements given in same order: body 31-37, 31-33, 29; trunk 17.0-20.5, 16.5-18.0, 17; tail 63-69, 67-69, 71; antedorsal 14.0-16.5, 13.5-14.0, 13; head 14-17, 14.5-15.5, 13.5; upper jaw 5.3-6.2, 5.5-5.6, 5.2; lower jaw 4.1-5.1, 4.1-4.3, 4; snout 3.8-4.1, 3.7-4.1, 3.8; eye 2.4-2.9, 2.4-3.1, 1.9; depth 4.5-6.8, 5.1-6.5, 4.7; pectoral 5.0-6.7, 4.9-5.7, 5; caudal 3.4-6.0, 2.2-5.2, 4.3. The lectotype from Trinidad, 240 mm: body 35, trunk 17.5, tail 65, antedorsal 16.5, head 18, upper jaw 5.8, lower jaw 4.9, snout 4.2, eye 3.2, depth 5.8, pectoral 6, caudal 4.9. As compared with like sized Gulf specimens, the Trini-

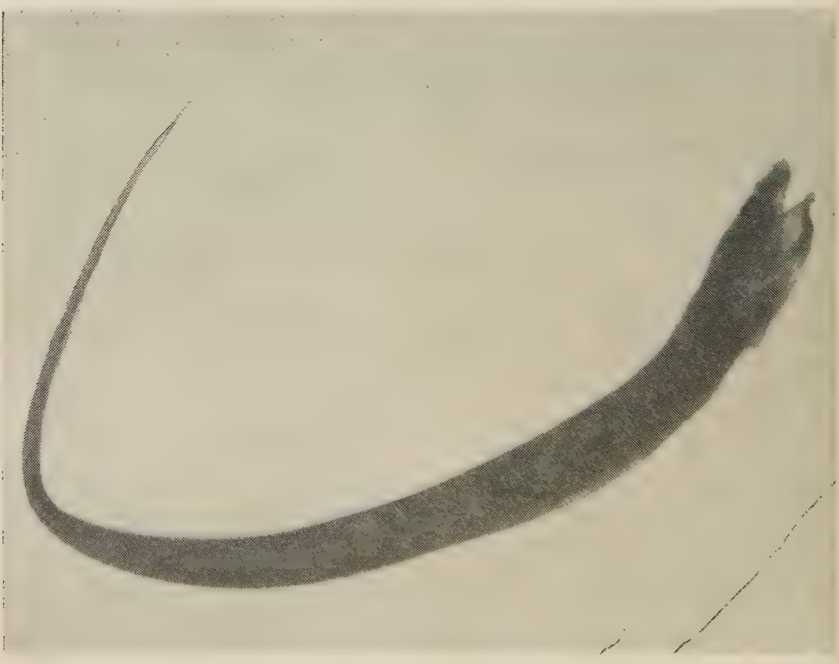

FIGURE 2.—*Congrina flava;* U. S. N. M. 155001; 183 mm; off Padre Island, Texas.

dad specimen has a moderately shorter tail and longer head. These might prove to be population differences.

Specimens examined from off the following localities: Trinidad (44612, the lectotype; 152573 taken with the lectotype). Yucatan (M.C.Z. 28080; Blake Station CCLXIV); Padre Island, Texas (154999 and 155001, collected by the Pelican); Mississippi Delta, Louisiana (155000 and 155004, collected by the Pelican; B.O.C. 3923-4, collected by the Atlantis); Dauphin Island, Alabama (B.O.C. 3927, Atlantis). Total examined 13 specimens 75-464 mm; taken in 14-89 fathoms.

LECTOTYPE—U. S. N. M. 44612. As two species were included in the original account, a specimen from off Trinidad, 240 mm, a drawing of which was published by the authors, is hereby designated as the lectotype.

The differences between *flava* and *macrosoma* and *gracilior* are discussed under the accounts of those two species. Structurally *flava* is nearest to *macrosoma.*

CONGRINA GRACILIOR, new species

Congermuraena flava Goode and Bean (in part), Ocean. Ichthy., p. 138, 1895 (The holotype and paratype have been separated from the specimens listed in the original account.)

Slender, tail notably tapering, becoming almost hair-like for some distance posteriorly. Palatal patch of teeth wedge-shaped; the posterior teeth in patch larger than anterior teeth, nearly large enough to be designated caninoid. Teeth in 4 irregular rows in upper jaw anteriorly, in 5 rows in lower jaw; palatal patch in 4 rows at widest part; premaxillary patch in about 8 irregular rows across and 5 along a longtitudinal axis.

Measurements of 2 specimens 135-202 mm: body 27, trunk 13.5-14.5, tail 73, antedorsal 13.0-13.5, head 12.5-13.0, upper jaw 4.8-5.0, lower jaw 3.7-3.8, snout 3.2-4.2, eye 2.6-3.0, depth 3.5-3.6, pectoral 3.9-4.2, caudal 2.2-2.5.

HOLOTYPE.—U. S. N. M. 44617; Albatross Station 2402, lat. 28° 36' N, long. 85° 33' 30" W; 111 fathoms; March 14, 1885; off Cape San Blas, Florida; 202 mm.

PARATYPE.—M.C.Z. 37165; Blake Station CCLXIV; lat. 23° 13' N, long. 89° 10' W; off Yucatan, Mexico; 84 fathoms; 135 mm.

This species compared with nearly like-sized specimens of *macrosoma, flava* (Goode and Bean) and *thysanochila* Reid (1934, p. 7), is strikingly more slender,

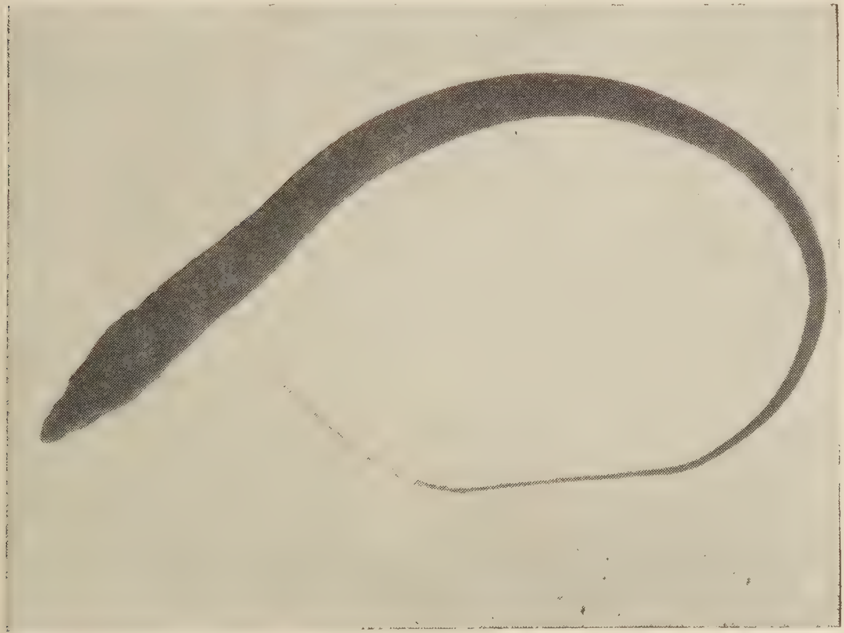

Figure 3.—*Congrina gracilior;* from the holotype; U. S. N. M. 44617; 202 mm; off Cape San Blas, Florida.

and its posterior end, for a considerable distance, is very attenuated, almost hair-like. It has a shorter body, trunk, antedorsal and head and a longer tail than the other three species. The palatal patch of teeth is wedge-shaped as in *thysanochila,* while the size of the teeth in the patch is intermediate between that species and the other two. In *thysanochila* the posterior teeth in the palatal patch are notably enlarged, canine to caninoid; in *macrosoma* and *flava* the teeth in the patch are subequal or the posterior teeth slightly enlarged; while in *gracilior* the posterior teeth are intermediate in size.

NEOCONGER Girard

Neoconger Girard, Proc. Acad. Nat. Sci. Philadelphia 10: 171, 1858 (genotype *Neoconger mucronatus* Girard by monotypy)

Chrinorhinus Howell Rivero, Proc. New England Zool. Club 13: 8, 1932 (genotype *Chrinorhinus torrei* Howell Rivero by monotypy)

This is a strongly marked genus, differing especially from all other congrid genera here treated by the point of insertion of the dorsal, over the vent or nearly so. The generic characters are included under the account of the single species described below where it is compared with another western Atlantic species of this genus.

NEOCONGER MUCRONATUS Girard

Neoconger mucronatus Girard, Proc. Ac. Nat. Sci. Philadelphia 10: 171, 1858 (St. Joseph Island, Texas)—Girard, U. S. and Mex. Bound. Survey, Ichthyology: 77, 1859 (St. Joseph Island, Texas)—Jordan and Davis, Rep. U. S. Comm. Fish 1888: 646, 1891 (after Girard)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47(1): 362, 1896 (after Girard)

Subterete, depth moderate; skin rather loose and preserved specimens often having a characteristic wrinkled appearance, forming a honeycombed or transversely ridged effect. Tail hardly tapering, except at the very end, a little shorter than body. Eye small, 2.3-3.4 in snout. Jaws and mouth small; lower jaw 3.1-3.8 in head; angle of mouth slightly behind eye, premaxillary teeth not exposed with mouth closed in normal position. Snout short, 4.6-5.2 in head, tapering, extending moderately beyond lower jaw. Upper lip continuous with skin of cheek or separated by a slight groove at posterior part of mouth; lower lip slightly better differentiated. Posterior nostril rather large, elongate, placed near eye and on a horizontal through its middle, with a slightly raised rim; anterior nostril smaller, without raised rim, at a moderate distance from end of snout. Tongue adnate or slightly free for a short distance in front. Gill opening transverse, placed on lower half of side, distance between the two fellows subequal to opening. Dorsal rather low, its origin sometimes over anus, usually a short distance more anteriorly; anal somewhat higher than dorsal. Pectoral short. Caudal of medium length. Teeth small, tapering, pointed, very moderately differing in different regions; in two irregular rows in jaws anteriorly, becoming one row posteriorly or one row throughout; palatal teeth in one or two rows anteriorly, one row posteriorly, reaching to opposite eye or nearly angle of mouth; premaxillary teeth in two short, slightly diverging rows, somewhat overlapping palatal and jaw teeth or closely approximated. Color in all specimens except one, yellowish without distinctive markings; a small specimen (98 mm) is much lighter than the others; one specimen having a closely woven reticulate pattern of very fine brown lines against a lighter background.

Measurements of 8 specimens 210-302 mm and 1 specimen 98 mm; body 51-53 (53), trunk 42-44 (42), tail 47-49 (47), antedorsal 48-52 (51); the following measurements determined on only 5 of the larger specimens: head 8.5-10.2 (11.5), upper jaw 2.9-3.8 (4.3), lower jaw 2.5-3.2 (3.8), snout 1.8-2.3 (2.4), eye 0.7-0.8 (0.9), depth 4.1-5.2 (3.6), pectoral 2.0-2.7 (1,8), caudal 2.6-3.3 (3.1). Contrary to the general trend in the ontogeny of eels, the small specimen of this species has the tail as short as in extreme variants of the large specimens, instead of being longer as in other eels.

Specimens examined from or off the following localities: Mississippi Delta, Louisiana (B.O.C. 29346, Atlantis). The following lots all from Texas: Padre Island (154997, Pelican); Corpus Christi Pass (154998, Pelican); St. Joseph Island (861, 4 cotypes). Total examined 9 specimens 98-302 mm. Depth records for all except the types, range 11-70 fathoms. The head of an eel which Woods (Copeia, 1942 (3): 191) identified as of this species, apparently does not belong to it, judged by the author's description.

Neoconger torrei (Howell Rivero), the holotype of which was examined (M.C.Z. 32786), differs from *mucronatus* as follows: the tail is slightly longer than the body, 51 per cent in length; the palatal teeth end slightly more forward, under anterior margin of eye; the tongue is free to a greater degree than in an extreme variant of *mucronatus.* The differences are slight and more adequate samples need to be compared directly, if these two species are really distinct. From all other Gulf eels *N.*

mucronatus is easily distinguished by the combination of its generic and specific characters.

HOPLUNNIS Kaup

Hoplunnis Kaup, Abh. Naturw. Ver. Hamburg 4(abt. 2): 19, 1860 (genotype *Hoplunnis schmidti* by monotypy)

Compressed, very slender. Tail tapering, much longer than body. Eye medium, 2.8-3.7 in long snout. Jaws somewhat beloniform, long (for an eel), slender, bony, covered with a moderate or thin skin; lower jaw somewhat narrower than upper, 1.9-2.1 in head. Mouth large, its angle a little behind eye. Premaxillary and jaw teeth exposed with the mouth closed. Snout long, 2.5-2.9 in head, a little projecting beyond lower jaw. Lips hardly or slightly differentiated from rest of skin. Posterior nostril large, elongate, with a very slightly raised rim, placed at a moderate distance in front of eye and opposite its middle; anterior nostril large, its rim well raised, not far from end of snout. A row of 4-5 large, elongate pores on lower part of cheek, at edge of jaw; a small pore in front of anterior nostril and another one farther in front, near tip of snout; 2 larger, widely spaced pores at some distance behind anterior nostril. Tongue adnate. Gill opening lateral but low, in front of and in large part below pectoral base, somewhat oblique or curving transversely, of medium extent, somewhat smaller than space between the two fellows or subequal to it. Dorsal origin at a moderate distance before gill opening; dorsal and anal fins rather well developed; pectoral moderate; caudal moderate to rather long. Teeth slender, pointed; in 2 or 3 irregular rows on side of jaws; lower jaw with a large upright tooth on a side near its anterior end (in 2 specimens a smaller tooth directly behind it on one side), 3-4 small teeth in a row in front of large tooth (in one specimen a small tooth forming part of a second row); inner row of teeth dissimilar in the two jaws, in lower jaw anterior inner teeth for greater part of jaw much larger than other jaw teeth, widely spaced in *diomedianus* and *macrurus,* close-set in *tenuis;* premaxillary teeth 5 in a curving row, the anterior or middle tooth largest, the posterior tooth very small (premaxillary teeth preserved in one specimen, in the other three specimens examined partly destroyed, but the traces left seem to agree with above statement). Midline of palate with a row of 6-8 very large, upright fangs; a median row of 2-4 small teeth directly in front of the large teeth, one similarly small tooth sometimes forming a rudimentary second row; small teeth beside or between the large teeth present or absent.

This genus is strongly characterized, especially by its dentition and jaws. The median row of palatal 6-8 fangs and the relative size and arrangement of the teeth in the jaws are unlike that of the other species here treated. The jaws are slender and uneel-like in appearance. In the shape of the jaws it approaches the genus *Nettastoma* Rafinesque. These two genera also have the dentiiton of a similar pattern, differing in that *Hoplunnis* has some of the teeth long, fang-like. Although the divergence is considerable the two genera are probably not too remote in relationship.

I found it very difficult to solve to my entire satisfaction the problem of speciation in the genus *Hoplunnis* with the available material, and my tentative solution here expounded is based to a large extent on the biologically unsatisfactory method of drawing conclusions by analogy, based on my experience in the study of intraspecific variability in other species of eels and fishes in general. Only four Gulf specimens of *Hoplunnis* were examined. The morphological differences between these four specimens are such as to make it seem likely that they belong to three species, considering intraspecific variability and interspecific differences in most other eels. Tentatively, the four specimens are so treated. Nevertheless, by some stretch of the imagination, the differences between these four specimens might be conceived as coming within the range of variability of a single species. On the other hand, offshore or deep water eels are difficult to obtain in numbers. It will probably be many years before adequate samples are obtained to determine intraspecific individual variability, ontogenetic changes and sex differences. Meanwhile, it is thought desirable to display the morphological differences between the four specimens by separating them into 3 species, and it is very probable that this treatment will prove to be correct.

Specimens of the genotype, *H. schmidti,* from Puerto Cabello, are not available for comparison. Judged by its account it differs from the three species here described as follows. Unlike *tenuis* and *diomedianus* it has two rows of teeth in the jaws. It

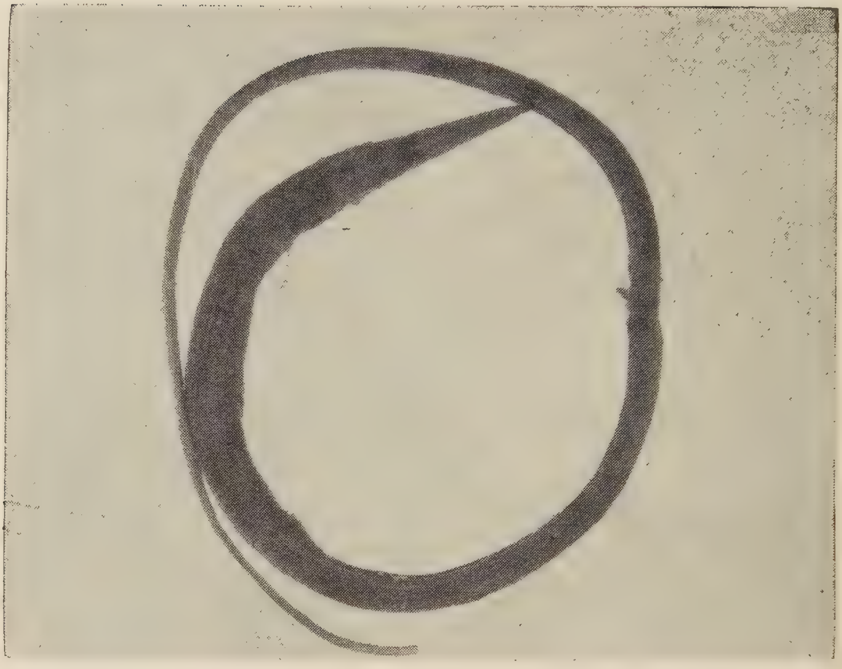

Figure 4.—*Hoplunnis tenuis;* from the holotype; U. S. N. M. 152574; 390 mm; off Cape San Blas, Florida.

differs from *macrurus* in having small teeth alongside the palatal fangs, and the figure indicates that it has a short caudal. It differs from all the three species in having 10 palatal fangs.

HOPLUNNIS TENUIS, new species

Notably tapering, becoming very attenuated and narrow at posterior end. Caudal damaged but apparently short. Teeth in jaws in 2 rows anteriorly, becoming 3 rows posteriorly for greater extent of jaw; teeth in outer row very small; teeth in inner two rows larger anteriorly becoming smaller posteriorly, near angle of mouth the teeth in the 3 rows subequally small, except those in inner row of lower jaw slightly larger than others; teeth in middle row similar in both jaws, moderately larger than those in outer row anteriorly, gradually decreasing in size posteriorly; anterior teeth in inner row of upper jaw slightly larger than those in middle row, gradually decreasing in size posteriorly; anterior teeth in inner row of lower jaw, for its greater extent, notably large as compared with outer teeth, nearly straight, 10 in number, very widely spaced, moderately decreasing in size posteriorly then becoming abruptly smaller and approximated at some distance before angle of mouth and also decreasing in size posteriorly. Large palatal teeth in median row 8 (a smaller tooth between the last two fangs); teeth in row flanking median row numerous, small, close-set. A row of moderate length having small teeth, in upper jaw near angle of mouth, on a line between outer band of teeth and midline of palate. (Small teeth in front of large canine of lower jaw destroyed.)

Specimen examined apparently faded; ground color light yellowish; upper aspect, and side of posterior part of tail, sprinkled with tiny dark spots, generally with diffuse boundaries, many of them in form of a ring, often having a black central point.

Measurements of a female 390 mm: body 25.5; trunk 14; tail 74.5; antedorsal 10; head 11.5; upper jaw 6.0; lower jaw 5.6; snout 4.6; eye 1.2; depth 2.7; pectoral 2.7; caudal damaged, probably close to 1.0.

HOLOTYPE.—U. S. N. M. 152574. Albatross Station 2402, lat. 28° 36' N, long. 85° 33' 30" W, off Cape San Blas, Florida; 111 fathoms; March 14, 1885; female with ripe eggs, 390 mm.

This species is nearest *diomedianus,* differing chiefly in having the anterior large teeth in the inner row of the lower jaw widely spaced and fewer, a row of teeth in upper jaw at angle of mouth behind the outer band, and 8 fangs on the palate. The antedorsal and head are longer than in *diomedianus*, and the small teeth on the palate alongside the fangs are smaller and much more numerous.

HOPLUNNIS DIOMEDIANUS Goode and Bean

Hoplunnis diomedianus Goode and Bean, Ocean. Ichthy., p. 146, pl. 43, fig. 163, 1895 (Albatross Station 2402; lat. 28° 36' N, long. 85° 33' 30" W; off Cape San Blas, Florida; 111 fathoms; longitude given in original account an error)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47(1): 361, 1896 (after Goode and Bean)

Hoplunnis schmidti Jordan and Evermann, ibid., pt. 4, pl. 58, fig. 151, 1900 (the figure, evidently a copy of that by Goode and Bean, bearing different name than text)

Notably tapering, becoming narrow and attenuated posteriorly. Caudal damaged but apparently short. Dentition about as described above for **tenuis** with the following exceptions: inner anterior teeth in lower jaw somewhat smaller, slightly curved, rather close set, 18-21 in number (counting on both sides); large palatal teeth in median row 6; teeth flanking median row somewhat larger, spaced, few (4 on right 3 on left); no row of teeth in upper jaw near angle of mouth entad of the outer band. Small teeth in front of large canine of lower jaw preserved, 3 on right side, 4 on left with a still smaller tooth in a second row.

Specimen examined apparently faded; ground color yellowish; with very small dark spots, very sparse anteriorly, somewhat more numerous on posterior part of tail; some of the spots in form of a tiny dark point surrounded by diffuse dark ring; caudal, and posterior part of dorsal and anal for a short distance, black.

Measurements of a male 424 mm: body 22.5; trunk 13.5; tail 77.5; antedorsal 7.6; head 9.2; upper jaw 4.6; lower jaw 4.5; snout 3.2; eye 1.1; depth 2.0; pectoral 1.7; caudal damaged, probably near 1.0.

LECTOTYPE—Goode and Bean state that they base their species on a "single individual." However, since they give the correct range of 6-8 for the large teeth on the "vomer" they apparently had more than one specimen. According to the National Museum catalog, the number given by the authors in the original account, 44240, contained 3 specimens one of which was deposited at Stanford. The jar bearing the given number now contains two specimens which were examined and found to represent two species. In order to avoid ambiguity one of these specimens, a male 424 mm, apparently the one figured and described in the original account, is here designated as the lectotype. The other specimen is here made the holotype of *tenuis*.

The species is nearest *tenuis* as discussed under that species.

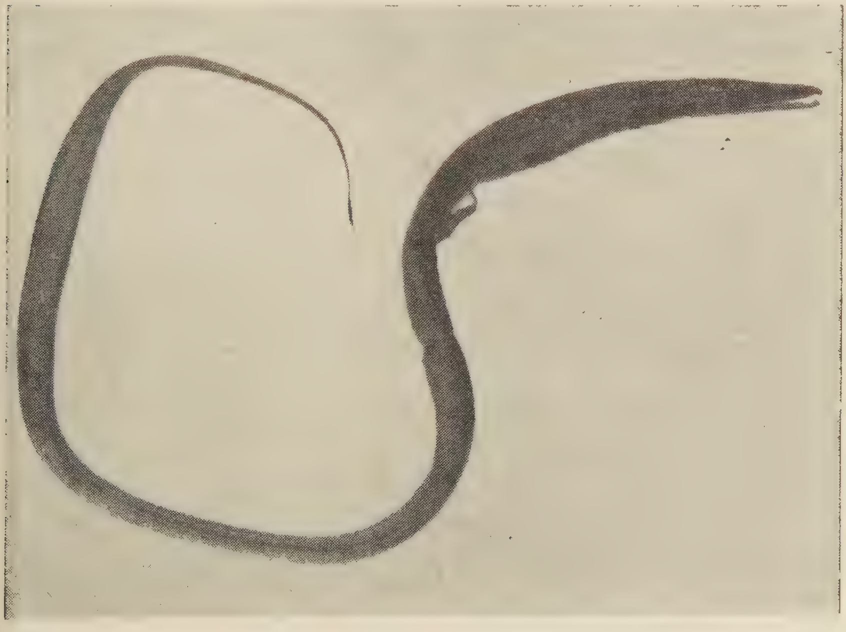

FIGURE 5.—*Hoplunnis macrurus:* from the holotype; U. S. N. M. 152565; 373 mm; off Mississippi Delta.

HOPLUNNIS MACRURUS, new species

Posterior taper moderate. Caudal notably long (for an eel). Teeth in jaws in 2 rows; teeth in outer row small; teeth in inner row of upper jaw moderately larger anteriorly, becoming smaller posteriorly to subequal outer teeth at angle of mouth; anterior teeth in inner row of lower jaw, for its greater part, large, nearly straight, widely spaced, 10-15 in number, decreasing in size posteriorly, at some distance before angle of mouth becoming rather abruptly smaller and close-set, at angle of mouth only slightly larger than outer teeth. Large palatal teeth in median row 6; no smaller teeth alongside main row; in female 3 small teeth on midline, one each on the posterior interspaces between the large teeth, these small teeth absent in male. Upper jaw without a row of teeth near angle of mouth behind outer band. Three small teeth in front of anterior large canine of lower jaw.

Ventral aspect and greater part of side light yellowish; dorsal aspect dusky, under magnification tiny black points surrounded by very narrow light area very sparsely scattered within dusky ground color; midback with a series of light colored spots against the dusky background; a narrow zone immediately below the dusky area thickly sprinkled with very small spots; the dusky area petering out at a moderate distance from end; the very small spots continued and spreading over this moderate posterior extent, rather profuse above, very sparse below; with a slight irridescent silvery tinge all over; caudal and posterior end of dorsal and anal black.

Measurements of 2 specimens 373-411 mm: body 24.0-25.5, trunk 13.5, tail 74.5-76.0, antedorsal 9.5-10.0, head 10.5-12.0, upper jaw 5.4-5.8, lower jaw 5.2-5.8, snout 3.8-4.3, eye 1.3, depth 2.4-3.0, pectoral 2.5-2.8, caudal 4.1-4.6.

HOLOTYPE.—U. S. N. M. 152565; lat. 29° 14' N, long. 88° 35' W; off Mississippi Delta, Louisiana; 40 fathoms; Stewart Springer; July 13, 1950; male, 373 mm.

PARATYPE.—U. S. N. M. 152566; lat. 29° 11' N, long. 88° 50' 30" W; off Mississippi Delta, Louisiana; 38 fathoms; Stewart Springer; September 12, 1950; female with ripe eggs, 411 mm.

The teeth in the inner row of the lower jaw of *macrurus* are as in *tenuis;* while the absence of a row of teeth in the upper jaw behind the outer teeth and the number of fangs on the palate are as in *diomedianus.* It differs from both in having 2, instead of 3, rows of teeth in the jaws. The posterior part of the tail is not as attenuated as in the other two species. The caudal of *macrurus* is rather unusually long, and it probably differs from *tenuis* and *diomedianus* also in this character; but this is not altogether certain because the caudals in the specimens examined of those two species are somewhat damaged.

DYSOMMINA, new genus

Genotype: *Dysommina rugosa,* new species

This genus differs from *Dysomma* by the more backward position of the vent and the more forward position of the dorsal origin. The two American species belonging to these two genera which were directly compared also differ considerably in the dentition as discussed below. The gill opening is horizontal instead of being vertical or nearly so. In the position of the vent and the dorsal origin, *Dysommina* nearly agrees with *Dysommopsis* Wood-Mason and Alcock (1891, p. 137) but differs from the latter in having pectorals.

Nettastoma brevirostre Facciola (1887, p. 166) appears to be another related species from the Mediterranean. Judged by its account, that species is either referable to *Dysommopsis* or should be referred to still another distinct genus. It seems to nearly agree with *Dysommopsis muciparus* in the relative positions of the dorsal origin, gill opening and vent, and in lacking pectorals; but the two species seem to differ in the dentition, although neither description is given in sufficient detail for constructive comparative purposes. Grassi and Calandruccio (1896, p. 349) did establish a genus *Todarus* based on *N. brevirostre* Facciola, without discussing its characters. However, the name *Todarus* is preoccupied, according to Neave's "Nomenclator Zoologicus."

DYSOMMINA RUGOSA, new species

Notably compressed, moderately deep. Tail moderately tapering, much longer than body. Eye rather small, 2.2 in snout. Mouth and jaws rather large; lower jaw 2.4 in head, narrow, fitting into a trough formed by upper jaw and its surrounding soft parts; anterior aspect of both jaws corrugated with transverse, well developed ridges formed by skin; angle of mouth under posterior margin of eye; teeth not exposed with the mouth closed. Snout 3.4 in head, blunt, extending a little beyond lower jaw. Upper surface of head to some distance behind eye, and lower jaw, with small papillae and tiny cilia-like outgrowths of skin, sparse posteriorly more numerous anteriorly. Upper lip not differentiated; lower lip separated by a slight groove at angle of mouth only. Posterior nostril notably large, placed at a short distance from eye, opposite its lower half, with a raised, slightly fimbriated border; anterior nostril in a short broad tubule, placed not far from end of snout. Pores rather small, 4 on lower part of cheek near rim of gape, almost but not altogether aligned in a lengthwise row, the first under anterior nostril, the fourth under middle of eye; one behind anterior nostril and one over it; a somewhat larger pore nearly in a horizontal line with latter, at some distance behind, and somewhat nearer midline. Tongue adnate. Gill opening low, alto-

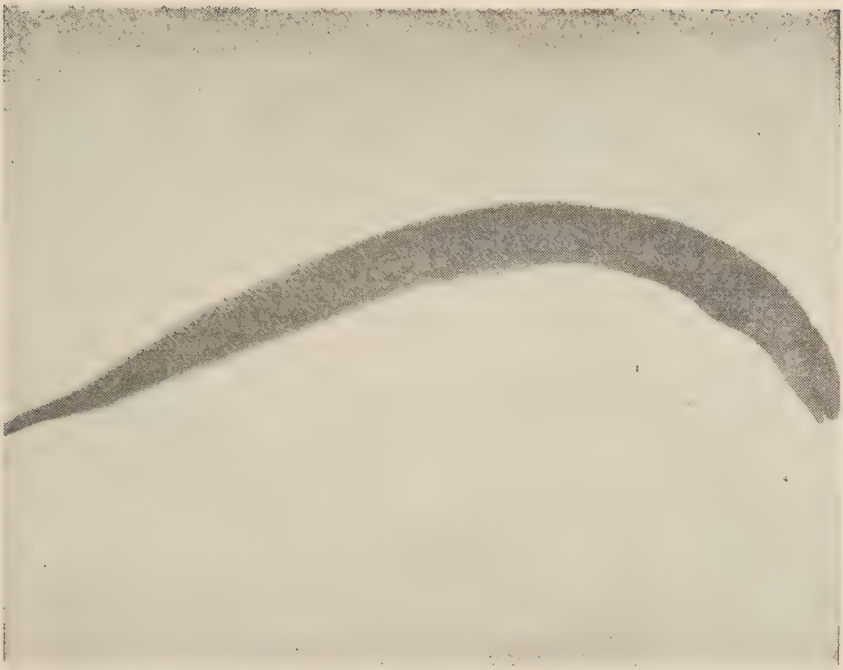

FIGURE 6.—*Dysommina rugosa;* from the holotype; U. S. N. M. 131594; 196 mm; off Cumberland Island, Georgia.

gether entering ventral as well as lateral aspect, placed horizontally, below and its greater part in front of pectoral base, of medium extent, subequal to distance between the two fellows. Dorsal origin at a short distance behind end of pectoral; dorsal and anal rather well developed; pectoral rather small; caudal comparatively well developed, truncate. Teeth in jaws small in bands of 4 irregular rows, extending from anterior end of jaws to angle of mouth; palatal teeth 4 moderate canines, widely separated, in a median row, the first placed a little behind beginning of jaw teeth, the fourth opposite anterior margin of pupil; each tooth placed in center of hummock of soft tissue; no premaxillary teeth (first tooth perhaps homologous with anterior 2 teeth on palate of **Dysomma aphododera**, see discussion below). Almost uniformly yellowish; the fins somewhat lighter; no distinctive markings.

Measurements of type specimen: body 28.0, trunk 13.5, tail 72, antedorsal 18.5, head 15.5, upper jaw 6.5. lower jaw 6.4, snout 4.4, eye 2.0, depth 5.6, pectoral 3.2, caudal 3.2.

HOLOTYPE—U. S. N. M. 131954. Albatross Station 2667; lat. 30° 53' N, long. 79° 42' 30" W; off Cumberland Island, Georgia; 273 fathoms; May 5, 1886; 196 mm.

The two American related species, *Dysomma aphododera* and *Dysommina rugosa* differ further, besides the characters discussed above under the genus, in the dentition as follows. In *D. aphododera* the band of teeth in the upper jaw is notably shorter than in *D. rugosa.* The dentition in the lower jaw of *D. aphododera* is different than that in the upper, consisting of a single row of larger teeth, while in *D. rugosa* the dentition in both jaws is similar. On the plate, *D. aphododera* has 3 spaced teeth on the midline preceded by two smaller teeth side by side; while *D. rugosa* has 4 spaced teeth on midline only. Therefore, for descriptive purposes *D. aphododera* is said to have premaxillary teeth, while *D. rugosa* is said to lack such teeth. However, these statements perhaps overemphasize the difference, as it is possible that the anterior median tooth of *D. rugosa* is properly homologous with the two anterior teeth of *D. aphododera.*

DYSOMMA Alcock

Dysomma Alcock, Ann. Mag. Nat. Hist. (6)4: 459, 1889 (genotype *Dysomma bucephalus* Alcock by monotypy)—Alcock, Descriptive Cat. Fish. Investigator, p. 192, 1899.

Dysomma is compared above under *Dysommina* with two related genera. It is distinguished from other congrid eels by the anterior position of the vent in combination with the moderate jaws, the narrow lower jaws and the dentition. The generic characters are included below under the description of *aphododera,* the one species here treated.

I am not altogether certain that *aphododera* is congeneric with *bucephalus,* the genotype of *Dysomma.* It nearly agrees with the published figure of that species in general appearance; and the position of the vent and the dorsal origin. However, the dentition of *bucephalus* is not described in sufficient detail for constructive comparison. These two species are further compared below. *Sinomyrus angustus* Lin (1933) is probably congeneric with *aphododera,* judged by its original description. Several other species have been described under *Dysomma* since it was first established, none of them from American waters. The several species described need to be compared directly, as it is possible that they are not all congeneric. References to these species are given by Bohlke (1949).

DYSOMMA APHODODERA, new species

Compressed, moderately deep. Tail moderately tapering, much longer than body; vent on a vertical through tip of pectoral or slightly before; trunk a little shorter than pectoral. **Eye small, 3.0-3.5 in snout. Jaws rather long**; lower jaw 2.5 in head, notably narrow, fitting into a trough formed by upper jaw and its surrounding soft parts; anterior aspect of both jaws corrugated by moderate, transverse ridges in the skin; teeth on side of upper jaw slightly exposed with the mouth closed. Mouth large, its angle at a considerable distance behind eye, a vertical through middle of eye about bisecting lower jaw. Snout 4.5 in head, blunt, extending a little beyond lower jaw. Upper surface of head to some distance behind eye, and lower jaw, with small tabs, numerous anteriorly, becoming fewer and smaller posteriorly. Upper and lower lip not differentiated. Posterior nostril large, with slightly raised rim, placed close to eye, at its lower part; anterior nostril not far from end of snout, in a short, broad tubule. Pores rather small; 4 pores in a row on cheek near rim of gape, the first a little behind anterior nostril, the fourth under posterior margin of eye; a pore behind anterior nostril, one over it, about halfway to midline, and another one a rather short distance behind latter. Tongue adnate. Gill opening low, its entire outline

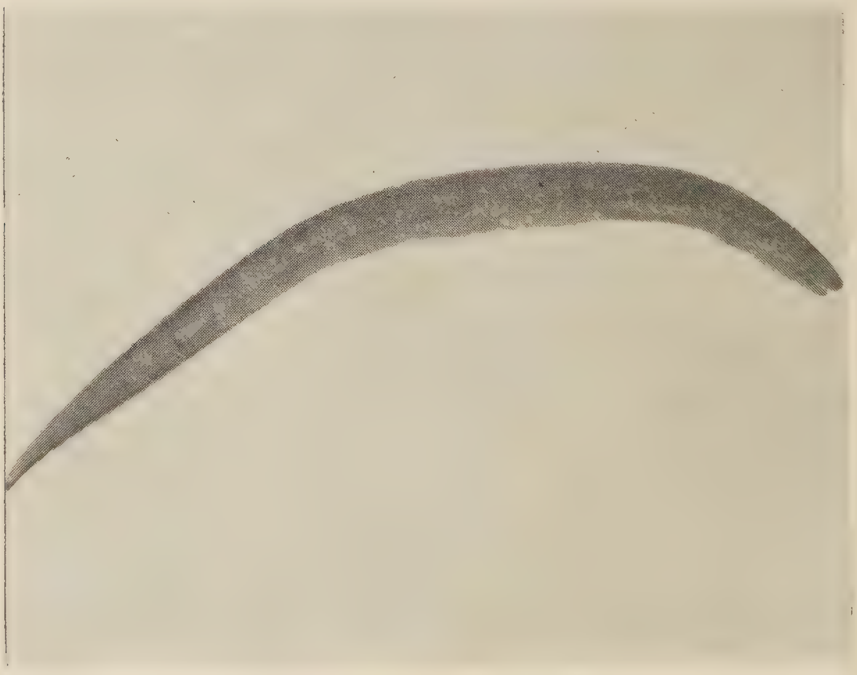

FIGURE 7.—*Dysomma aphododera;* from the holotype; U. S. N. M. 154992; 218 mm; off Padre Island, Texas.

entering ventral as well as lateral aspect, placed under pectoral base, its position oblique but more inclined to the vertical, rather small, subequal to space between the two fellows. Dorsal origin a little in front of pectoral base; dorsal, anal, pectoral and caudal moderately developed. Teeth in upper jaw small, pointed, in a narrow band having two irregular rows anteriorly and three posteriorly, the inner teeth somewhat larger than outer, the band beginning at some distance from anterior end of jaw, about opposite first palatal canine, and ending at some distance before angle of mouth; teeth in lower jaw much larger than those in upper jaw, in one row, widely spaced, about 7 on a side; palatal teeth largest of all, 3 straight, widely spaced canines in a lengthwise row on midline, the last one opposite eye; premaxillary teeth 2, side by side, somewhat larger than teeth in lower jaw; each tooth, except those in upper jaw, surrounded by a thick, conical hummock of soft tissue. Yellowish, nearly uniform, anterior ventral aspect somewhat lighter; no distinctive markings.

Measurements of 2 specimens 218-226 mm: body 17.5-18.5, trunk 2.5-3.2, tail 81-83, antedorsal 13.5, head 14.5-15.5, upper jaw 6.4-6.9, lower jaw 5.7-6.2, snout 3.2-3.5, eye 1.0-1.1, depth 5.6-5.7, pectoral 3.7-3.9, caudal 2.7-2.8.

HOLOTYPE.—U. S. N. M. 154992. Pelican Station 117-1; lat. 26° 30' N, long. 96° 26' W; off Padre Island, Texas; 50 fathoms; February 5, 1939; 218 mm.

PARATYPE.—U. S. N. M. 154993. Pelican Station 108-11; off Port Aransas, Texas; 37 fathoms; 226 mm.

As compared with the account of *D. bucephalus* Alcock (see citation under genus) *aphododera* differs in having the position of the vent a little more backward in relation to the position of the pectoral, and the pectorals shorter. Very likely other differences will appear on direct comparison of specimens.

Table 1.—Frequency distribution of the tail length in 3 species of *Gymnothorax*, segregated by size; expressed as a percentage of the total length.

species	length of specimens in mm	distribution														
		45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
saxicola	285 - 380									5	5	4	1			
nigromarginatus	294 - 376												1		3	2
ocellatus	344 - 366												2	1		
saxicola	395 - 447						2	3	3	5	1					
nigromarginatus	390 - 452										1			1	3	2
ocellatus	388 - 431										1	2		1		
saxicola	471 - 583	1	1	1	1	2	1	1								
nigromarginatus	611											1				
ocellatus	497 - 542										1	1				

Table 2.—Frequency distribution of the trunk length in 3 species of *Gymnothorax*, expressed as a percentage of the total length.

species	length of specimens	distribution												
		26	27	28	29	30	31	32	33	34	35	36	37	38
saxicola	285 - 380				1	2	8	1	2	1				
nigromarginatus	294 - 376		1	3	1	1								
ocellatus	344 - 366				1		1	1						
saxicola	395 - 447					3	2	3	2	2	1	1		
nigromarginatus	390 - 452	1	2	1	1	2								
ocellatus	388 - 431						1	1	1		1			
saxicola	471 - 583							2		1	1	1	1	2
nigromarginatus	611							1						
ocellatus	497 - 542								1	1				

Table 3.—Frequency distribution of the head length in 3 species of *Gymnothorax*, expressed in thousandths of the total length.

species	length of specimens	distribution																
		110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190
saxicola	285 - 380							2	2	6		1	3	1				
nigromarginatus	294 - 376						1	2	1	1	1							
ocellatus	344 - 366		1			1	1											
saxicola	395 - 447						1			2	2	3	2	3		1		
nigromarginatus	390 - 452						1	3	1	2								
ocellatus	388 - 431	1		1	1	1												
saxicola	471 - 583												4		1	1	1	1
nigromarginatus	611				1													
ocellatus	497 - 542				1		1											

Table 4.—Frequency distribution of the depth of the body in 3 species of *Gymnothorax*, expressed in thousandths of the total length.

species	specimens	distribution													
	length of	45	50	55	60	65	70	75	80	85	90	95	100	105	110
		depth measured just before anus													
saxicola	285 - 380	1		7	4	3									
nigromarginatus	294 - 376		1	3	1	1									
ocellatus	344 - 366			1	1	1									
saxicola	395 - 447			1	4	3	3	2		1					
nigromarginatus	390 - 452		1	3	2	1									
ocellatus	388 - 431			1	2	1									
saxicola	471 - 583					2	2		2						
nigromarginatus	611	1													
ocellatus	497 - 542					1	1								
		depth measured at gill opening													
saxicola	285 - 380				1	2	4	2	1	4	1				
nigromarginatus	294 - 376			1		2		3							
ocellatus	344 - 366				1			1	1						
saxicola	395 - 447								1	3	6	2	1	1	
nigromarginatus	390 - 452				2		3	1	1						
ocellatus	388 - 431					1	1	1	1						
saxicola	471 - 583									1	3	2		1	1
nigromarginatus	611					1									
ocellatus	497 - 542								1	1					

Table 5.—Frequency distribution of the length of the lower jaw in 3 species of *Gymnothorax*, expressed in thousandths of the total length.

species	length of specimens	distribution											
		46	49	52	55	58	61	64	67	70	73	76	79
saxicola	285 - 380		2	1	2	3	1	3		1	1		
nigromarginatus	294 - 376	1	2	3									
ocellatus	344 - 366	1			1	1							
saxicola	395 - 447			1			2	9		1		1	
nigromarginatus	390 - 452	1	1		3	2							
ocellatus	388 - 431		1	2		1							
saxicola	471 - 583						1		1	2	2	1	1
nigromarginatus	611				1								
ocellatus	497 - 542				2								

Table 6.—Frequency distribution of the snout length in 3 species of *Gymnothorax*, expressed in thousandths of the total length.

species	length of specimens	distribution					
		23	26	29	32	35	38
saxicola	285 - 380		6	3	4	2	
nigromarginatus	294 - 376	1	2	3			
ocellatus	344 - 366	2		1			
saxicola	395 - 447		1	5	4	3	1
nigromarginatus	390 - 452		4	3			
ocellatus	388 - 431	1	3				
saxicola	471 - 583			3	2	2	1
nigromarginatus	611	1					
ocellatus	497 - 542	2					

Table 7.—Frequency distribution of the numerical value of the ratio of the tail divided by the head in 3 species of *Gymnothorax.*

species	length of specimens	distribution								
		2.5	2.8	3.1	3.4	3.7	4.0	4.3	4.6	4.9
saxicola	285 - 380			3	4	6	2			
nigromarginatus	294 - 376					1	3	2		
ocellatus	344 - 366							2		1
saxicola	395 - 447		1	6	6	1				
nigromarginatus	390 - 452					1	3	3		
ocellatus	388 - 431							1	2	1
saxicola	471 - 583	3	3	2						
nigromarginatus	611							1		
ocellatus	497 - 542						1	1		

FAMILY MURAENIDAE

Three species belonging to this family, comprised within one genus, occur in the northern part of the Gulf. They may be distinguished from other Gulf eels by their small gill opening in combination with the absence of a pectoral, the medium or rather large mouth with strong jaws, and the single row of rather broad, subtriangular, shark-like teeth in the jaws. Characters common to the three species and one South American species which is here included for comparative purposes, are stated under the following account of the genus.

GYMNOTHORAX Bloch

Gymnothorax Bloch, Ichthyologie ou Histoire Naturelle . . . des Poissons, pt. 12, p. 67, 1797 (genotype *Gymnothorax reticularis* Bloch by subsequent designation)—Internat. Comm. Zool. Nomencl., opinion 93, in Smithsonian Misc. Coll. 73(4):5, 1926 (*Gymnothorax reticularis* fixed as the genotype by the plenary power of the commission).

Variably stout anteriorly, well tapering posteriorly. Tail longer than body or moderately shorter. Eye and snout medium; mouth and jaws medium to rather large, angle of mouth behind eye, a vertical through middle of eye about bisecting lower jaw or slightly nearer angle of mouth; usually upper jaw slightly longer than lower, sometimes the lower jaw slightly longer, often the two jaws subequal. Premaxillary teeth not exposed with the mouth closed. Lips not differentiated. Posterior nostril medium, without a raised margin, placed a little above eye, on or directly behind a vertical through its anterior margin; anterior nostril ending in a tubule, near end of snout, on a horizontal through middle or lower margin of eye. Tongue adnate. Gill opening equalling eye diameter, varying a little both ways, placed on middle of side or a little below. Dorsal and anal rather well developed, continuous with caudal, the dorsal becoming notably high in large specimens. Dorsal origin placed in advance of gill opening. (It is difficult to localize with precision the point of origin of the dorsal in the species of this genus without dissection. Hence, the point of origin given under the species accounts is approximate only. Especially, the antedorsal measurements given below are very roughly approximate.) Pectoral absent. Teeth in jaws rather broad, compressed, tapering, in a single row, posterior and greater number of teeth rather abruptly smaller than a few anterior teeth, subtriangular, pointing upward and backward, somewhat shark-like; premaxillary teeth indistinguishably forming one continuous row with teeth on side of upper jaw; a median row of small palatal teeth placed notably backward, beginning at a point opposite eye (sometimes a few teeth beside main row); anterior palatal fangs present or absent depending on the species.

KEY TO THE SPECIES OF GYMNOTHORAX

a. Teeth entire; 2-3 median anterior fangs on palate; with a light reticulate pattern against dark background .... *moringa* (p. 459).
aa. Teeth in jaws serrate; without median fangs on palate; with whitish spots against a darker background.
b. Anal usually almost solid black or brown; dorsal typically with a broad, black or brown interrupted margin. Head 12.6-18.9.
c. Tail 45-54 in the larger specimens; dark lengthwise lines on head usually well marked; white spots larger .... *saxicola* (p. 461).
cc. Tail 54-59 in the larger specimens; dark lengthwise lines on head very faint or absent; white spots typically smaller and more widely spaced. .... *nigromarginatus* (p. 461).
bb. Anal usually with a series of spots resembling the segments of a circle; dorsal typically with a series of bands arranged in pairs. Head 11.2-13.7. Tail 54-57. White spots rather large and widely spaced .... *ocellatus* (p. 463).

GYMNOTHORAX MORINGA (Cuvier)

Muraena maculata nigra Catesby, Natural History of Carolina, Florida and the Bahama Islands, vol. 2, pl. 31, 1738

Muraena moringa Cuvier, Regne Animal, ed. 2, vol. 2, p. 352, 1829 (based on Catesby)—Gunther, Cat. Fish. Brit. Mus. 8: 120, 1870 ("Tropical parts of the Atlantic")—Jordan, Proc. U. S. Nat. Mus. 7: 197, 1885 (Catesby's plate identified)

Gymnothorax moringa Goode, Bull. U. S. Nat. Mus. 5: 72, 1876 (Catesby's plate identified with specimens from Bermuda)—Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 601, pl. 75, 1891 (Pensacola to Rio de Janeiro and St. Helena)

Lycodontis moringa Jordan and Evermann, Bull. U. S. Nat. Mus. 47: 395, pl. 65, fig. 171, 1896 (Pensacola to Rio de Janeiro and St. Helena)

Moderately stout anteriorly becoming notably so in large specimens. Tail longer than body. Eye 2.1-2.4 in snout; lower jaw 2.0-2.2 and snout 4.8-5.3 in head. Gill opening subequal to eye diameter or a little larger. Dorsal origin on a vertical nearer gill opening than angle of mouth or midway between. Teeth entire; 2-3 large moveable fangs in a median row on palate a little behind premaxillary teeth, widely separated from posterior row of small palatal teeth; 2 anterior teeth at symphysis somewhat smaller than teeth immediately following.

General color brown with irregular, tortuous yellow lines forming a reticulate pattern extending on the dorsal and anal; on underside of head and trunk yellow color expanded and color pattern may be described as a yellow ground color irregularly spotted with brown.

Measurements of 2 specimens 879-894 mm and 2 specimens 579-704 mm: body 45-47 (43-44), trunk 31 (29), tail 54-55 (56-57), antedorsal 11.5-12.0 (11), head 14.5-17.0 (14.0-15.5), upper jaw 7.1-8.0 (6.6-7.0), lower jaw 7.2-7.8 (6.4-6.9), snout 2.9-3.6 (2.8-2.9), eye 1.3-1.5 (1.3-1.4), depth 6.8 (6.3-7.9).

Localities for the above 4 specimens: Gulf of Mexico (43948, sent in fresh by a New Orleans fish dealer, exact locality not given). Key West (35036) and Garden Key (6794), Florida. The specimens examined, except possibly the first one listed. are not from the northern Gulf coast. Baughman (1950, p. 128) states that Reeve M. Bailey identified a specimen from Freeport, Texas in the U. M. M. Z. as belonging to this species.

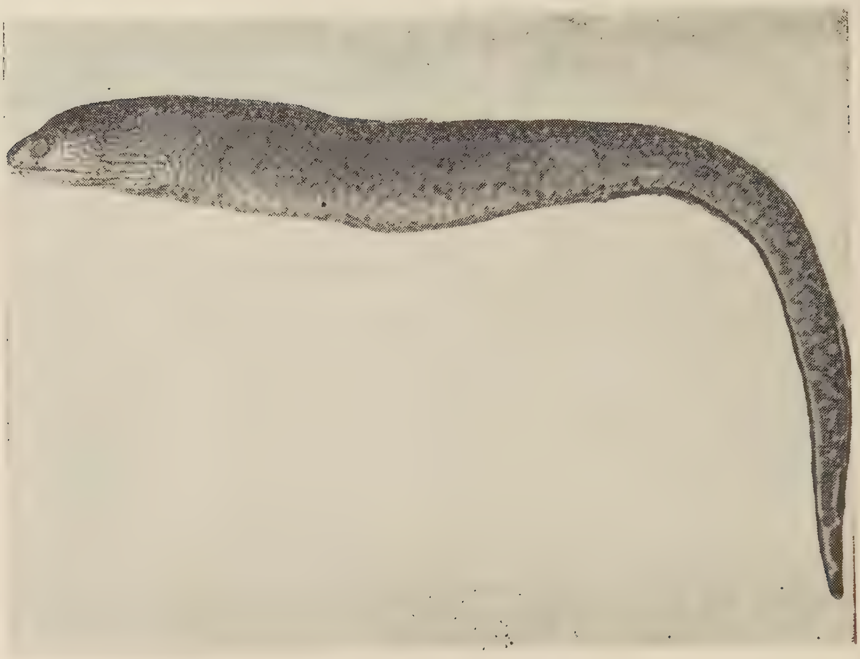

FIGURE 8.—*Gymnothorax saxicola;* U. S. N. M. 152241; 420 mm; off Pensacola, Florida.

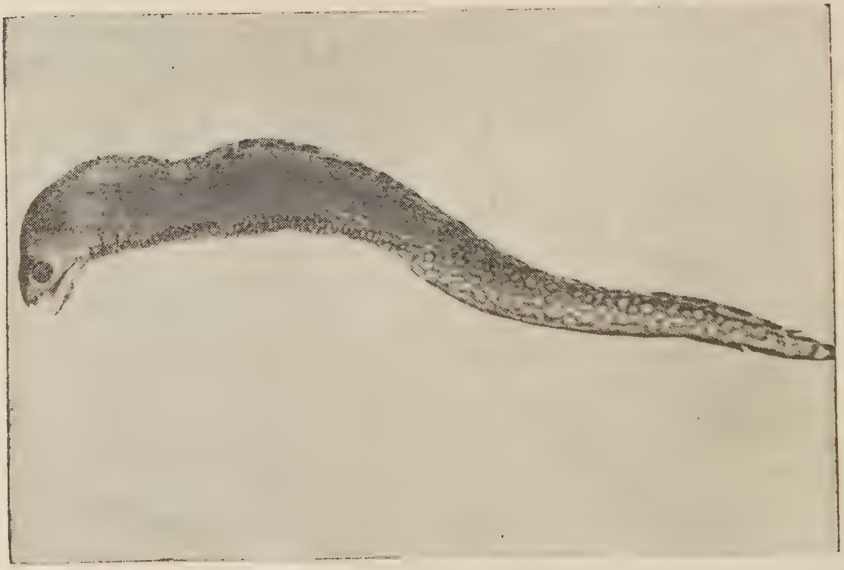

FIGURE 9.—*Gymnothorax saxicola;* U. S. N. M. 154989; 395 mm; off Charleston, South Carolina.

This species is readily distinguished from all Gulf eels by its distinctive color pattern. As compared with the other two Gulf muraenid species it differs in having entire, instead of serrated, teeth in the jaws, and in having 2-3 anterior, moveable fangs on the midline of the palate.

GYMNOTHORAX SAXICOLA Jordan and Davis

Gymnothorax ocellatus var. *saxicola* Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 606, 1891 ("abounds about the Snapper Banks")

Lycodontis ocellatus saxicola Jordan and Evermann, Bull. U. S. Nat. Mus. 47(1): 399, 1896 (Pensacola Snapper Banks; Cuba)

In medium sized specimens rather stout anteriorly, and tail usually longer than body, sometimes subequal to it; stouter, tail shorter than body in large fish. Eye 1.3-1.8 in snout; lower jaw 2.2-2.9 and snout 4.5-6.0 in head. Gill opening subequal to eye diameter or a little smaller. Dorsal origin on a vertical midway between angle of mouth and gill opening, varying a little both ways. Teeth in jaws rather well serrated on anterior and posterior margin, except anteriormost teeth usually serrated on posterior margin only; row of small palatal teeth very variable, usually 6-10 in number, varying 2-13; anterior fangs on midline of palate absent; teeth at symphysis subequal to teeth immediately following.

Ground color on side and dorsal aspect brown of a variable shade of intensity, sometimes with a grayish tinge; with whitish rounded spots against the darker background; spots relatively large (as compared with **nigromarginatus**), usually subequal to interspaces or nearly so, often rather smaller than interspaces; in the smaller specimens spots often wider than interspaces, the darker color then forming a reticulate pattern around the spots; ventral aspect almost uniformly whitish or yellowish, except in the larger specimens color pattern of sides often faintly continued on ventral aspect; an area on side and underside of head, directly behind gill opening, with well marked, lengthwise, dark streaks more or less irregular and anastomosing; a moderate extent near end of fish with white, lengthwise, oblique or confluent bands; dorsal with a broad black or dark brown margin, interrupted (might also be described in other words as margin having a series of short bands), sometimes continuous or nearly so for a variable distance at posterior part of fish; anal usually almost all black or brown.

Measurements of 9 specimens 380-471 mm: antedorsal 11.5-15.0, upper jaw 5.7-8.0, eye 1.7-2.5.

Specimens examined from or off the following localities: Cape Lookout and Cape Fear, North Carolina; Charleston, South Carolina; Cumberland, Sapelo and Ossabaw Islands, Georgia; Amelia Island, Biscayne Bay, Key West, Cape Sable, Clearwater Harbor, Cedar Keys, Cape St. George, Cape San Blas and Pensacola, Florida; Mobile, Alabama. The available depths for some of these lots range 11-50 fathoms. Total number of specimens examined 39, 249-583 mm, including 4 taken in Florida without more definite locality records. The largest specimen is from Charleston.

NEOTYPE—U. S. N. M. 34280; Cedar Keys, Florida; Henry Hemphill; 430 mm. As no type appears to have been set aside by Jordan and Davis, the above specimen is hereby designated as the neotype. The authors mention Cedar Keys in their account and the specimen designated is possibly one of those examined by them; but there is no way now of definitely identifying their specimens.

This species is very close to *nigromarginatus* and the differences between them are discussed under the account of that species.

GYMNOTHORAX NIGROMARGINATUS (Girard)

Neomuraena nigromarginata Girard, Proc. Acad. Nat. Sci. Philadelphia 10: 171, 1858 (St. Joseph's Island, Texas)—Girard, U. S. Mex. Bound. Surv., p. 76, pl. 41, 1859 (based on same specimen)

Gymnothorax ocellatus var. *nigromarginatus* Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 606, 1891 (based on type)

Lycodontis ocellatus nigromarginatus Jordan and Evermann, Bull. U. S. Nat. Mus. 47(1): 399, 1896 (Pensacola; St. Joseph's Island, Texas)

Moderately stout anteriorly in the larger specimens. Tail longer than body. Eye 1.4-2.0 in snout; lower jaw 2.3-3.3 and snout 4.7-6.0 in head. Gill opening somewhat smaller than eye diameter. Dorsal origin on a vertical usually nearer gill opening than angle of mouth, sometimes midway between. Dentition virtually the same as that described above for **saxicola**.

General color pattern about the same as in **saxicola** differing from that species as follows: white spots smaller than in **saxicola**, smaller than interspaces, sometimes subequal to interspaces in the smaller specimens; dark lengthwise streaks on head rather faint or imperceptible; a moderate distance near end of fish with comparatively large, rounded or elongate white spots.

Measurements of 7 specimens 391-452 mm: antedorsal 11.0-13.5, upper jaw 5.3-6.4, eye 1.2-2.0.

Specimens examined from or off the following localities: Padre Island, St. Joseph Island and Galveston, Texas; Point au Fer, Isle Derniere, Mississippi Delta,

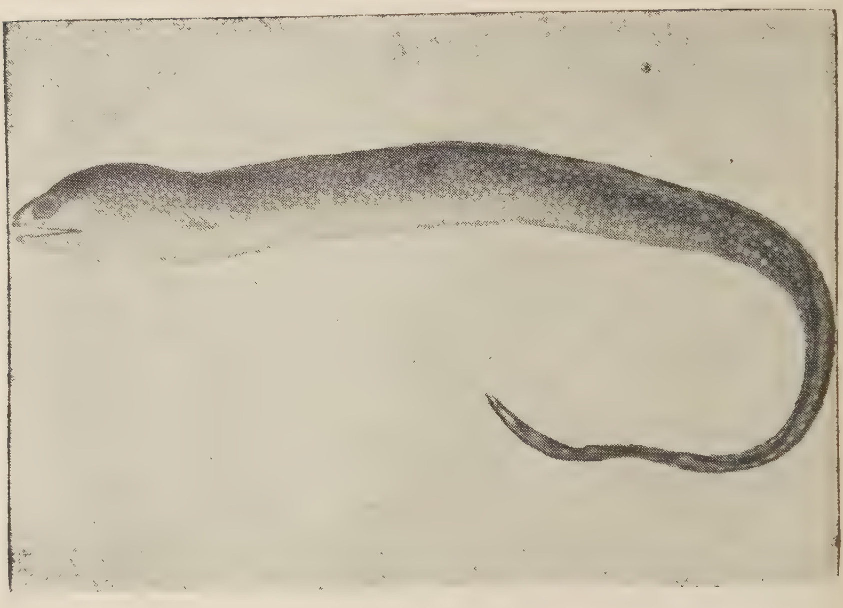

FIGURE 10.—*Gymnothorax nigromarginatus;* U. S. N. M. 131153; 433 mm; off Morgan City, Louisiana.

and Errol Island, Louisiana; Pensacola, Florida. Depth records are available for 9 out of 12 lots and range 10-35 fathoms. Thirteen specimens examined, 294-452 mm, six of which were obtained by the Pelican and 3 by the Atlantis.

In addition to the above 13 specimens, one large specimen, 611 mm. (M.C.Z. 35110) from Pensacola, differs considerably in its proportional measurements, as shown in tables 1-7. Its shorter head and more slender body are notable, especially in consideration of the regular changes in growth shown by the other two species. Two suggestions might be made to explain these differences. First, it might be suggested that it is an abnormal specimen. It is abnormally large in size for its species; and correlated with its unusual size, its body proportions are also abnormal. Second, it is possible that the normal growth changes in this species, when the specimens attain to a relatively large size are different than in the other two species with which it is here compared.

NEOTYPE.—U. S. N. M. 7004; St. Joseph Island, Texas; Wurdemann; 391 mm. According to Girard's account his type specimen bears U. S. N. M. number 860; but that number cannot now be located. The specimen designated as the neotype bears the same data as Girard's original specimen, and judging by his plate, it is also of the same length. Consequently, it is very likely that it is Girard's original type and that inadvertently it has been entered twice in the National Museum catalog.

This species is very close to *saxicola* and single specimens cannot always be identified with certainty. The bulk of specimens, especially the larger specimens, are distinguishable at a glance by differences in the color pattern. In typical *nigromarginatus* specimens the white spots are smaller, and the lengthwise lines on the head are faint or absent, instead of being well marked as in typical *saxicola.* In comparing the size of the spots it should be noted that in both species, in general, the spots relatively decrease in size with growth and specimens of approximately like size are best compared. Sixteen of the specimens of both species examined were collected recently by the Fish and Wildlife research boat 'Pelican" and by the "Atlantis." The others preserved for longer periods, some of them for 60 years or more, generally show the color pattern fairly well.

The two species also differ in proportional measurements. Seven such measurements are presented in tables 1-6. They are of differing degrees of divergence, and intergrade more or less with the extent of intergradation more pronounced in the smaller specimens. The greatest degree of divergence is shown by the tail length which intergrades very moderately in the two smaller size groups. The length of the lower jaw intergrades widely in the smaller specimens, less so in the larger fish. However, the latter measurement is not as reliable as that of the tail, because it is not susceptible of precise determination. Of the characters determined the least degree of divergence is shown by the snout length. One ratio between two of these measurements, the tail length divided by that of the head (table 7), shows a moderate degree of intergradation in the larger fish.

All in all, it is evident that we are dealing here with two distinct, but morphologically more or less overlapping populations. In general, the differences between them are somewhat like the differences between two subspecies of the same species; but the degree of divergence is perhaps greater than what is usual between two coordinate subspecies. This combined with the fact that the two populations also overlap geographically at least over a part of their ranges perhaps makes it desirable to treat them as two independent species.

GYMNOTHORAX OCELLATUS Agassiz

Gymnothorax ocellatus Agassiz, Selecta genera et species piscium . . . Brasiliam, p. 91, pl. 50b, 1829 (Brazil)

Moderately stout anteriorly in the larger specimens. Tail longer than body. Eye 1.4-1.9 in snout; lower jaw 2.2-2.5 and snout 4.3-5.6 in head. Gill opening subequal to eye diameter or a little smaller. Dorsal origin nearer gill opening than angle of mouth. Dentition virtually as described under **saxicola** except that the serrations are rather weaker.

General color pattern very similar to that of **saxicola** and **nigromarginatus**, with white spots against a darker background; the white spots about as large as in **saxicola**, but rather more widely spaced than in that species, the interspaces generally wider than the spots somewhat as in **nigromarginatus**; lengthwise dark lines on head well marked or faint (the latter perhaps due to fading, specimens examined having been preserved for about 85 years); dorsal typically with a series of short, wide, somewhat oblique, black or brown bands, usually arranged roughly in pairs, the interspace between the two in the pair less than preceding and following interspace, a streak on margin of fin of same color as bands bridging over interspace between the two in a pair, but not the space between adjacent pairs; bands often very short not extending far below margin (color pattern of dorsal of such variants approaching that of **saxicola** or **nigromarginatus**), often the two bands in the pair more or less fused, becoming normally so for some distance near end of fish; anal with a series of spots in form of segments of a circle with the curved side proximad, the straight side usually coalesced with adjacent ones forming a continuous dark margin for the fin.

Measurements of 10 specimens 242-542 mm: antedorsal 8.5-12.0, upper jaw 4.8-5.9, eye 1.3-1.9.

The above 10 specimens from Rio de Janeiro, Brazil (M.C.Z. 9067 and 9086).

The typical color pattern of the dorsal and anal in *ocellatus* is unlike that of *saxicola* and *nigromarginatus;* although there is considerable variation and individual variants sometimes approach those two species in the color of the fins. The white spots are usually as large as in *saxicola,* but rather widely spaced as in *nigromarginatus.* In most proportional measurements (see tables 1-6) *ocellatus* nearly agrees with *nigromarginatus,* in the trunk length it is nearer to *saxicola,* while the head is shorter than in both northern species.

FAMILY ECHELIDAE

Species belonging to this family have, like the Ophichthidae, the posterior nostril placed on the lower lip or the edge of the gape. They differ from the Ophichthidae in having a caudal fin, the dorsal, anal and caudal fin fold being continuous around the posterior end of the fish. Two species of this family, belonging to separate genera, occur in the Gulf.

KEY TO THE SPECIES OF ECHELIDAE

a. Dorsal origin in front of vent. Palatal teeth in two rows anteriorly becoming one row posteriorly, extending to opposite angle of mouth. .... *Myrophis punctatus* (p. 464).

aa. Dorsal origin behind vent. Palatal teeth one or two only, placed between beginning of rows of jaw teeth; without a band or row of teeth on midline of palate........ *Ahlia egmontis* (p. 465).

MYROPHIS Lütken

Myrophis Lütken, Vidensk. Medd. Naturh. Foren. Copenhagen 1851: 14, 1852 (genotype *Myrophis punctatus* Lütken by monotypy)

This genus is compared with *Ahlia* under the account of that genus.

MYROPHIS PUNCTATUS Lütken

Myrophis punctatus Lütken, Vidensk. Medd. Naturh. Foren. Copenhagen 1851: 15, pl. 1, figs. 2 and 2b-d, 1852; also, in a translation of the article in Archiv Naturg., Jahrg. 18, bd. 1, p. 270, 1852 (said to have been brought by an expedition to the West Indies, locality not stated)—Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 640, 1891 (West Indian Fauna, from Texas to Surinam)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47: 371, 1896 (West Indian Fauna, coast of Texas to Surinam)—Parr, Bull. Bingham Oceanog. Coll. 3(4): 12, 1930

Myrophis lumbricus Jordan and Gilbert, Proc. U. S. Nat. Mus. 5: 261, 1882 (Galveston, Texas)

Slender, compressed or rounded. Tail longer than body, moderately tapering. Eye medium, 1.3-2.3 in snout, covered by thick skin. Mouth and jaws moderate; lower jaw 3.4-4.5 in head; angle of mouth at some distance behind eye, a vertical through middle of eye about bisecting lower jaw or a little nearer angle of mouth; premaxillary teeth covered or moderately exposed with the mouth closed. Snout rather blunt, moderately projecting beyond lower jaw, 5.7-7.9 in head. Upper lip not differentiated; lower lip separated by a groove for about its posterior half or more, narrow. Posterior nostril large, located on rim of gape, just in front of a vertical through anterior margin of eye, its outer half with a rather wide, flaring border, its inner margin not raised; anterior nostril placed near lateral profile, at a short distance from end of snout, in a short tubule, broader at the base, its distal margin irregularly sinuate, its upper part with a small somewhat pointed tab. Tongue adnate. Gill opening lateral, somewhat oblique, rather small, less than the distance between the two fellows. Dorsal origin usually midway between gill opening and vent or moderately nearer vent, sometimes a little nearer gill opening; dorsal, anal and caudal fins rather low, continuous around posterior end. Pectoral moderate (for an echelid). Teeth rather small, pointed, moderately differing in size; no canines; teeth in upper jaw in two irregular rows; anterior teeth of lower jaw somewhat larger and in two rows, in one row posteriorly; palatal teeth in two rows anteriorly, in one row posteriorly, the teeth growing smaller backward and extending approximately to opposite angle of mouth; premaxillary teeth in one arched row, usually 5 in number, varying 3-7; jaw, palatal and premaxillary teeth in rather close proximity to one another.

Ground color yellowish or brownish; anteriorly lower half a nearly uniform color, upper half or so very thickly peppered with tiny dark specks, the speckled part increasing in width posteriorly to cover nearly entire side near posterior end of fish.

Measurements of 7 specimens 223-356 mm and 4 specimens 121-146 mm: body 39-41 (38-40); trunk 30-31 (28-29); tail 58-61 (60-62); antedorsal 24-29 (24.5-26.0); head 9.0-10.5 (9-11); upper jaw 2.5-3.3 (2.5-3.2); lower jaw 2.1-3.1 (2.1-3.0); snout 1.3-1.8 (1.2-1.9); eye 0.6-0.9 (0.6-1.1); depth 2.7-3.2 (2.7-3.4); pectoral 1.3-2.2 (1.0-1.5); distance from dorsal origin to vent 11.5-15.5 (12.0-14.5), 1.9-2.6 (2.0-2.4) times in trunk.

Specimens examined from the following localities: Corpus Christi, Aransas Pass, Copano Bay, Warwick Bayou and Galveston (including the type of *Myrophis lumbricus*, 30896), Texas; Grande Isle, Louisiana; Biloxi, Mississippi; Dauphin Island, Alabama; Boca Grande and Fort Jefferson, Florida; Beaufort, North Carolina. The largest specimen is 356 mm, from Beaufort.

One large specimen, 426 mm, landed at Freeport, Texas, by a fishing boat, presumably taken off the coast of Texas, and submitted by J. L. Baughman differs from the smaller specimens on which the above account is based, as follows. The teeth are more numerous; in three irregular rows in the upper jaw; in two rows in the lower jaw; in three rows on the palate tapering to one row posteriorly. Many of the teeth are comparatively stouter and not as pointed as in the smaller specimen. The premaxillary teeth are absent, but the bone is irregularly pitted and it seems as though teeth were present in earlier life. Its other characters, as well as its proportional measurements, agree with or fall within the range of variation of the smaller specimens. It is darker than the smaller specimens; but the densely puncticulate color pattern of *punctatus* is evident, although somewhat obscure. It is evidently an individual of this species, the differences noted being due to its size.

The smaller specimens of this species are apparently taken along the coast, generally in muddy places; although habitat data for most constituent samples examined are lacking. The large specimen, brought in by a fishing boat, was very likely taken offshore. The fragmentary data available would then seem to suggest that the smaller specimens live inshore and move out offshore to attain to some size.

AHLIA Jordan and Davis

Ahlia Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 639, 1891 (genotype *Myrophis egmontis* Jordan by original designation and by monotypy)

This genus differs from *Myrophis* Lütken by the absence of a row of palatal teeth. Parr (1930) reduces *Ahlia* to the synonymy of *Myrophis* chiefly because of the discovery of new species showed that the position of the dorsal origin, one of the two characters by which the two genera were formerly distinguished, cannot be maintained. He then suggests the possibility that the difference in the dentition might be a growth character. However, I examined small specimens of *A. egmontis,* as small as 57 mm, and find that the dentition is essentially as in the adult, including the lack of a median palatal row of teeth. As the palatal dentition is one of the main characters, perhaps the primary character, that is currently used for separating echelid genera, and it is in general of generic importance in the classification of apodal fishes, it seems that the difference in the dentition is enough to maintain Ahlia as distinct from *Myrophis,* at least tentatively, until the family is revised. As to the dorsal origin, it appears that in many related echelid species, this character differs widely with the species and varies intraspecifically to a considerable extent. Consequently, this character, as it relates to such species, is best considered as being important at the species level only.

The status of *Ahlia* is also discussed by Myers and Storey (1939, p. 158) and Wade (1946, p. 199), who conclude that it deserves recognition.

AHLIA EGMONTIS (Jordan)

Myrophis egmontis Jordan, Proc. Acad. Nat. Sci. Philadelphia 36: 44, 1885 (Egmont Key, Florida)—Parr Bull. Bingham Ocean. Coll. 3(4): 9, 1930 (included in key)

Ahlia egmontis Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 639, 1891 (based on type)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47: 730, pl. 60, fig. 158, 1896 (based on type)

Slender, compressed. Tail longer than body, moderately tapering. Eye medium, 1.3-2.3 in snout. Mouth and jaws moderate; lower jaw 3.5-4.0 in head; angle of mouth at a moderate distance behind eye, a vertical through middle of eye nearer angle of mouth than tip of lower jaw; premaxillary teeth covered or a little exposed with the mouth closed. Snout blunt, moderately projecting beyond lower jaw, 5.1-6.1 in head. Upper lip not differentiated; lower lip partly differentiated by a short groove at angle of mouth. Posterior nostril large, placed at rim of gape, its larger part within the gape, under anterior margin of eye, its outer anterior part only with a wide, flaring, soft margin; anterior nostril a broad, low tubule, placed at lateral profile a short distance from end of snout, upper margin of tubule indented, with a narrow, short tab rising from low point of indentation. Tongue adnate. Gill opening lateral, moderately oblique, rather small, less than space between the two fellows. Dorsal origin at a moderate distance behind vent; dorsal, anal and caudal moderately developed, continuous around posterior end. Pectoral moderate (for an echelid), subequalling snout. Teeth in jaws in one row; in upper jaw the rows from the two sides approach closely in front; palatal teeth two, side by side, or one on midline, placed so as to bridge space between the two rows of jaw teeth or slightly in front; premaxillary teeth 3-5, in a curved row. Color almost uniformly yellowish or brownish in gross effect, without definite color marks visible to naked eye; under magnification tiny, almost microscopic, dark dots appear, very densely sprinkled over entire fish except lower part of head and trunk and fins.

Measurements of 3 specimens 329-410 mm and 2 specimens 209-276 mm: body 42-43 (40-41), trunk 33-34 (33), tail 57-58 (59-60), antedorsal 43-45 (44-45), head 8.4-8.9 (7.9-8.4), upper jaw 2.6-2.7 (2.5-2.7), lower jaw 2.2-2.4 (2.1-2.3), snout 1.4-1.5 (1.4-1.6), eye 0.8-1.0 (0.6-0.9), depth 2.7 (2.0-2.7), pectoral 1.3-1.7 (1.0-1.6), distance vent to dorsal origin 1.2-3.0 (3.6-4.7).

Specimens examined from the following localities in Florida: Egmont Key (the type, 35086), Boca Grande, Alligator Reef, Tortugas. The largest specimen is 410 mm.

This species is readily distinguished from *Myrophis punctatus,* its nearest relative in the Gulf by the position of the dorsal origin behind the vent, the presence of only one row of teeth in the jaws and the absence of a row of palatal teeth.

FAMILY OPHICHTHIDAE

Scales absent. Moderately stout to excessively slender and worm-like. Tail longer than body to shorter than trunk. Mouth small to very large, upper jaw longer than lower and premaxillary teeth, when present, more or less exposed, except in *Mystriophis* jaws subequal in front. Lips partly or almost wholly separated by a groove, or continuous with surface of head. Posterior nostril large, rounded, partly or wholly surrounded by a raised membranous edge, placed on lip (or in a position normally occupied by the lip, when lip indistinguishable), under anterior margin of eye or more forward, except in *Verma* a narrow slit placed just above lip. Anterior nostril opening in a bulging tubule, or a spheroidal protuberance, except in *Letharchus*, placed nearly in a horizontal line with posterior nostril. Tongue adnate, except in *Mystriophis* and *Gordiichthys*. Gill opening transverse, oblique, or lengthwise in large part, moderate or large. Dorsal, anal and pectoral fins present or absent: caudal absent, the dorsal and anal, when present, terminating at some distance before end of tail, leaving posterior point without fin fold. Teeth tapering, pointed, small to large, moderately or hardly differing in size in different series in most genera; palatal and jaw teeth in one to four irregular rows, depending on the species, and also on intraspecific change with growth in some species; premaxillary teeth in a single arched row, moderately or well separated from palatal and jaw teeth, except absent in *Letharchus*.

For practical purposes, based on readily determinable, external characters, fishes of this family are recognized by the finless posterior point, and by the position of the posterior nostril, placed on the lip or just above it.

KEY TO THE OPHICHTHID EELS HERE TREATED

a. Lips differentiated by a well marked groove. Posterior nostril an elongate or oval slit, without a raised flaring rim, with a straight flap attached entad of the upper margin; placed directly above groove separating lip. All fins absent. Tail longer than body. Worm-like .... *Verma kendalli* (p. 468).

aa. Lips not differentiated or only slightly so near angle of mouth. Posterior nostril variably large, rather rounded, with a broad flaring edge; placed on rim of gape, or slightly above. Dorsal present (hidden in *Cryptopterygium* and visible externally as a slight ridge); anal and pectoral present or absent.

b. Dorsal origin behind gill opening. Posterior nostril moderately large, placed a little above rim of gape and at some distance in front of eye (except in *Ophichthus gomesii*). Tail longer than body. Pectoral rather well developed. Comparatively stout eels, with a variably large gape and strong jaws and dentition (except in *O. gomesii*). Teeth in jaws extending their entire length.

c. One or two teeth on palate and 2-4 anterior teeth on side of each jaw notably larger than others, canine. Tongue free. Jaws subequal in front .... *Mystriophis* (p. 468).

d. Largest spots in medium sized specimens subequal to distance from tip of snout to posterior margin of eye, roughly in 3 lengthwise rows at widest part of spotted area (spots change in size and number with growth, see descriptions and discussion in text) .... *Mystriophis intertinctus* (p. 470).

dd. Largest spots in specimens of about comparable size subequal to snout, roughly in 3 lengthwise rows .... *Mystriophis mordax* (p. 470).

ddd. Largest spots in specimens of about comparable size a little smaller than snout, roughly in 6 lengthwise rows .... *Mystriophis punctifer* (p. 474).

cc. Teeth medium to rather large, their size only moderately differing in the different series. Tongue adnate. Snout moderately projecting beyond lower jaw .... *Ophichthus* (p. 475)

e. Tail 53-57; lower jaw 2.1-2.5 times in head. Palatal teeth in one row, except 2 teeth side by side in front of row present or absent. Posterior nostril moderately large, placed a little above edge of gape and at some distance before eye. With a median row of white spots. Teeth rather large.

f. Dorsal origin over end of pectoral or at a moderate distance more forward or slightly behind. Antedorsal distance 14.0-17.5. White spots comparatively large, eye divided by largest spots equalling 0.7-1.4 .... *Ophichthus ocellatus* (p. 476).

ff. Dorsal origin behind a vertical through pectoral end at a distance nearly equalling snout length. Antedorsal distance 19.0. White spots rather small, the largest 2 in eye .... *Ophichthus guttifer* (p. 476).

fff. Dorsal origin behind a vertical through pectoral end at a distance a little over three snout lengths, nearly equalling postorbital part of head. Antedorsal distance 23.5. White spots subequal to eye .... *Ophichthus retropinnis* (p. 477).

ee. Tail 62-67; lower jaw 2.8-3.2 times in head. Palatal teeth in 2 rows, becoming 4 irregular rows in large specimens. Posterior nostril notably large, placed on rim of gape under anterior margin of eye. Without a median row of white spots. Teeth moderate. Dorsal origin over pectoral end or a short distance more forward .... *Ophichthus gomesii* (p. 478).

bb. Dorsal origin before gill opening, on a vertical a little behind angle of mouth. Posterior nostril notably large, placed on rim of gape under anterior part of eye. Tail shorter than body. Pectoral very small or absent. The depth moderate or notably slender, with small mouth and rather weak jaws. Snout tapering, well overhanging lower jaw.

g. Anterior mandibulary teeth moderately or slightly larger than posterior ones; anterior palatal, and premaxillary teeth, when present, moderately large. Tongue adnate (unknown for *Cryptopterygium*).

h. Dorsal, and anal when present, exposed.

i. Pectorals very small. Gill opening lateral, transverse or oblique, the distance between the two fellows subequal to opening. Tail subequal to trunk or moderately shorter, tail 44-47, trunk 47-50. Very slender, subterete to moderately compressed, the depth 1.1-2.6. Teeth in upper jaw beginning before eye and ending a short distance from angle of mouth. Anal present .... *Bascanichthys* (p. 478).

j. Depth 1.7-2.6, 2.2-3.1 times in head; upper jaw 1.2-1.8 times in depth .... *Bascanichthys teres* (p. 479).

jj. Depth 1.1-1.6, 3.4-5.4 times in head; upper jaw 0.7-1.0 times in depth .... *Bascanichthys scuticaris* (p. 480).

ii. Pectorals absent. Gill opening placed low, near ventral profile, its outline altogether visible when viewed from ventral aspect, running lengthwise in large part, the space between the two fellows less than the opening. Tail much shorter than trunk; tail 39-41; trunk 51-54. Moderately elongate, compressed, the depth 2.2-3.0. Row of teeth in upper jaw very short beginnning under eye and ending some distance from angle of mouth.

k. Anal fin and premaxillary teeth present *Callechelys muraena* (p. 480).

kk. Anal fin and premaxillary teeth absent *Letharchus velifer* (p. 481).

hh. Dorsal and anal fins hidden under the skin, visible externally as a slight ridge. Tail 33, trunk 61. Slender, compressed, depth 1.7 .... *Cryptopterygium holochroma* (p. 482).

gg. Anterior mandibular teeth rather well or notably larger than posterior ones; anterior palatal and premaxillary teeth well enlarged (perhaps enough so to be designated canine). Tongue free (unknown for *irretitus*). Tail 35-36, trunk 58. Body excessively elongate, wormlike, the depth 0.9-1.3 .... *Gordiichthys* (p. 483).

1. Palatal teeth in one row, anterior 4 large, posterior 6 abruptly smaller .... *Gordiichthys irretitus* (p. 483).

11. Palatal teeth 5, large, in two rows; no small teeth behind anterior large ones .... *Gordiichthys springeri* (p. 484).

VERMA Jordan and Evermann

Verma Jordan and Everman, Bull. U. S. Nat. Mus. 47(1): 374, 1896 (genotype *Sphagebranchus kendalli* Gilbert by monotypy)

This genus differs from all other eels here treated by the absence of all fins. The posterior nostril, in its position and structure, differs from other ophichthid eels (and from echelids as well), and it is doubtful whether this genus properly belongs to the Ophichthidae.

VERMA KENDALLI Gilbert

Sphagebranchus kendalli Gilbert, Bull. U. S. Fish. Comm. 9: 310, 1891 (off Turkey Key, Florida; 25 fathoms)—Jordan and Davis, Rep. U. S. Comm. Fish 1888: 615, 1891 (based on type)

Verma kendalli Jordan and Evermann, Bull. U. S. Nat. Mus. 47(1): 375, 1896 (apparently based on original specimen)

Very slender, rounded, vermiform. Tail longer than body, moderately tapering for a rather short distance. Eye very small, 1.8-2.9 in snout. Mouth and jaws medium; lower jaw 3.5-4.8 in head; angle of mouth at a considerable distance behind eye; tip of lower jaw only a short distance in front of vertical through anterior margin of eye; premaxillary teeth slightly or hardly exposed with the mouth closed. Snout rather long, 5.3-5.8 in head, tapering, notably projecting beyond lower jaw. Lips differentiated by a well developed groove, except for a short distance in front. Posterior nostril an elongate narrow or oval slit, without a raised edge, with an oval flap attached a little within its upper margin, placed just above groove separating lip, under anterior margin of eye; anterior nostril a broad somewhat elongate tubule, placed on ventral aspect of snout, near lateral profile, at some distance from end of snout. Tongue adnate. Gill openings medium, oblique, placed very low, its complete outline better viewed from ventral than lateral aspect, the space between the two fellows narrower than opening. All fins absent. Teeth small, pointed, tapering; no canines; in one row in jaws and on palate; palatal teeth extending to a short distance behind a vertical through posterior margin of eye; premaxillary teeth moderately larger than others, in a V-shaped row, typically 5 in number, often any one tooth in row missing; jaw, palatal and premaxillary teeth rather well spaced. Color a nearly uniform yellowish, sometimes with a grayish or purplish tinge; no distinctive markings in preserved specimens.

Measurements of 5 specimens 171-311 mm: body 45-47, trunk 40-41, tail 53-55, head 6.0-6.3, upper jaw 2.2-2.8, lower jaw 1.3-1.8, snout 1.1 in all, eye 0.4-0.6, depth 1.2-1.4.

Specimens examined, including the type (44304), taken on the coast of Florida in 25-42 fathoms, off the following localities: Turkey Key, Key West, Fowey Rock, Miami. The largest specimen is 311 mm.

This species is readily distinguished from all eels here treated by the following combination of characters: its extremely slender, vermiform body, the characteristic overhanging long, tapering snout, the structure and position of the posterior nostril, the absence of all fins and the dentition.

MYSTRIOPHIS Kaup

Mystriophis Kaup, Cat. Apod. Fish. Brit. Mus., p. 10, 1856 (genotype *Ophisurus rostellatus* Richardson by monotypy)

Echiopsis Kaup, ibid., p. 13 (genotype *Ophisurus intertinctus* Richardson by monotypy)

Crotalopsis Kaup, Abhand. Naturw. Ver. Hamburg 4 (abt. 2): 12, 1860 (genotype *Crotalopsis punctifer* Kaup by monotypy)

Moderately deep, moderately tapering for a rather short distance posteriorly, subterete to moderately compressed. Tail a little longer than body. Eye medium, 1.5-2.7 in short snout. Mouth and jaws large; lower jaw 1.8-2.1 in head; angle of mouth far behind eye, posterior margin of eye considerably nearer tip of snout than angle of mouth; jaws subequal in front or upper slightly longer than lower. Snout rather short, 6.3-8.3 in head, very moderately tapering. Lips not differentiated. Posterior nostril moderately large, placed slightly above rim of gape and a little in front of eye, its outer rim widely flaring, inner rim slightly or moderately flaring; anterior nostril placed rather close to posterior one, with a moderately raised suborbicular tubule. Tongue moderately free. Gill opening placed on lower half of side, transversely curved, large, wider than the distance between the two fellows. Dorsal origin behind a vertical through end of pectoral at a distance about equal to pectoral length, varying a little both ways; dorsal and anal fins rather well developed; anal having a variable stretch, at a short distance from its end, lower than parts immediately preceding and following; a similar stretch on dorsal usually of lesser development. Pectoral moderately developed. Teeth tapering, pointed; size of teeth differing widely in different positions, some of them conspicuously large, canine; teeth in jaws extending over their entire length; palatal and jaw teeth in two rows for their greater part, the two rows in the jaw well separated; teeth in lower jaw in one row anteriorly, in two rows on side for nearly its entire length, the posterior 2 to 4 teeth in the anterior single row rather large, canine, graduated, growing larger posteriorly, the teeth in the outer row directly behind canines small, increasing in size posteriorly, becoming large on middle of side, but not as large as anterior canines, then decreasing again backward to angle of mouth, teeth in inner row small, not notably differing in size; relative size of teeth on side of upper jaw about same as in lower, except some small teeth, in front of anterior 2-4 canines, placed directly over anterior canines of lower jaw, anterior canines of upper jaw placed directly over the small teeth following the canines in lower jaw, teeth in inner row of upper jaw somewhat larger than similarily placed teeth in lower jaw; premaxillary teeth 4-9 in a single curved row, decreasing in size from symphysis backward, well or moderately separated from teeth on side of jaw; one large straight canine, the largest of all, on midline of palate, at a short distance behind premaxillary teeth, very often a second tooth very close to and before, beside or behind it, the second tooth, when present, usually smaller, sometimes the two teeth subequal, posterior palatal teeth comparatively small, in two rows converging backward and becoming a single row for a short distance posteriorly, not reaching to opposite angle of mouth, often a few additional teeth forming additional rudimentary one or two rows; the small palatal teeth separated by a short interval from the one or two anterior canines.

Ground color usually yellowish or brownish sometimes grayish, with a pinkish tinge; the ventral aspect moderately or notably lighter than upper part, uniformly colored; upper part for about half or two-thirds the width spotted; spots on head very small or mere dark points, thickly sprinkled, becoming larger on nape; dorsal and anal with a dark or black margin, continuous or interrupted.

Mystriophis differs from *Ophichthus* in having well developed canines; the snout is shorter and does not project beyond the lower jaw, and the mouth is larger. It differs from all ophichthid genera here treated, except *Gordiichthys*, in having the tongue moderately free.

Jordan and Davis (1891,p. 634) place the species here described in the genus *Mystriophis*, and this treatment was generally followed by later authors. However, the type of that genus, *Ophisurus rostellatus* Richardson (1844, p. 105), is described by its author, and by Gunther (1870, p. 56), as having the palatal teeth canine and in a single row. It is, therefore, possible that it is generically distinct from the species here included in *Mystriophis*. If so, our species should be placed in *Echiopsis*. But lacking specimens of *rostellatus* for comparison current usage is here followed.

Structural characters given under the genus heading are practically the same in the three species here treated and are not repeated under their accounts. The size and number of the spots differs with the species and intraspecifically with growth. The spots are not arranged in definitely regular rows, especially in the species in which the spots are numerous. However, in order to present the differences between the species they are described as though they were in rows. The number of rows as stated under the species descriptions rather refers to the number of spots touched by an imaginary very narrow transverse band placed across the widest part of the spotted area.

The characteristic color pattern of every species evidently does not fade except after very long immersion in preservative. It is well marked in every specimen forming the basis of the following accounts of the species. A few specimens examined that were preserved nearly 100 years ago are partly faded and are not included in these accounts.

I have been unable to solve with a measure of satisfaction the problem of speciation among the Gulf eels of the genus *Mystriophis* by means of the available material. Proportional measurements and the dentition are nearly alike in the specimens examined, or they do not indicate any possible differences of specific magnitude. They differ conspicuosly in the color pattern, in the relative size and number of the spots. A comparison of large available specimens shows such a striking difference in the color pattern that taxonomists will generally agree that more than one species is involved. The main difficulty is that the size and number of spots change with growth. They decrease in relative size and increase in number as the fish grows. Therefore, in order to distinguish the species properly by the color pattern, it is necessary to have an adequate sample in a graded size range in every species and compare specimens of approximately like size. Such a necessary collection of specimens is not now available. Consequently, a final and definitive solution of the problem must await the accumulation of more extensive collections.

Tentatively, based on the scant number of specimens examined, three Gulf species are here distinguished by color only. What is presumably the type of one species, *mordax*, was examined. The proper application of the other two names, *intertinctus* and *punctifer*, the types of which were not examined, is attended with a considerable measure of doubt.

Three large specimens of *punctifer*, 890-1190 mm, compared with 2 specimens of *mordax* 940-1110 mm, and 3 specimens of *intertinctus* 842-977 mm, have the spots much smaller and much more numerous. The 3 specimens present such a strikingly different appearance that there is hardly any question that they belong to a distinct species. While it is difficult to express such a difference in terms of definite figures, it is decidedly abrupt without any gradually intergrading specimens. In a 646 mm specimen of *punctifer* the spots are relatively larger and less numerous than in the large specimens of the same species; but distinctly smaller and more numerous than in comparable specimens of the other two species.

The difference in the color pattern between *mordax* and *intertinctus* is not as striking as between either one of these species and *punctifer*. When compared size for size, the spots in *mordax* are smaller than in *intertinctus* (but notably larger than in *punctifer*) and more widely spaced. The difference in appearance is such as to indicate to a high degree of probability that the specimens examined represent two distinct species.

MYSTRIOPHIS INTERTINCTUS (Richardson)

Ophisurus intertinctus Richardson, Voy. Erebus and Terror, p. 102, 1844 (West Indies)

Ophichthys intertinctus Gunther, Cat. Fish. Brit. Mus. 8: 57, 1870 (West Indies)

Mystriophis intertinctus Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 635, 1891 (West Indian fauna, north to western Florida)

In specimens 230-372 mm largest spots larger than distance from tip of snout to posterior margin of eye, roughly in 2 lengthwise rows, without smaller interpolated spots; in specimens 728-842 mm largest spots slightly larger than snout and eye combined, roughly in 3 lengthwise rows, a few smaller spots interpolated between the larger ones; in specimens 958-977 mm largest spots subequal to snout and eye combined or slightly smaller, roughly in 4 rows, a moderate number of smaller spots interpolated between the large ones.

Specimens examined from off or at the following localities: Cape Fear, North Carolina (151927, 151981); Clearwater Harbor (23635) and Pensacola (17126, 32758), Florida; west Florida (22865, 49797); St. Thomas (6956, specific identification of locality not given). Altogether 8 specimens examined 230-977 mm. The largest specimen is from off Cape Fear; the largest Gulf specimen is 842 mm from Pensacola.

This species is recognized by its large spots as discussed under the account of the genus.

MYSTRIOPHIS MORDAX (Poey)

Conger mordax Poey, Mem. Hist. Nat. Cuba 2: 319, 1860 (Cuba)

Macrodonophis mordax Poey, Rep. Fis. Nat. Cuba 2: 252, pl. 2, fig. 9, 1867 (Cuba)—Poey, Syn. Pisc. Cub., p. 425, 1868 (Cuba)

Crotalopsis mordax Poey, Enum. Pisc. Cub., p. 153, 1876 (Cuba)

Table 8.—Ranges of proportional measurements of three species of *Mystriophis*, segregated in size groups, expressed as a percentage of standard length.

species	length of specn.	number of specn.	body	trunk	tail	antedorsal	head	upper jaw	lower jaw	snout	eye	depth	pectoral
intertinctus	307-372	2	46.0-47.0	33.5-35.5	53.0-54.0	16.0-17.0	12.0	5.9-6.6	5.6-6.4	1.4-1.8	0.9-1.2	3.8	2.6-3.9
mordax	351-473	2	46.5	34.0-35.0	53.0-53.5	16.5-18.0	12.5	6.2-6.4	6.1-6.2	1.6-1.8	0.9	3.9-4.1	3.3-3.6
intertinctus	728	1	47.5	36.5	52.5	16.0	11.5	5.9	5.8	1.6	0.6	4.3	3.0
mordax	671	1	47.0	35.5	53.0	15.5	11.5	6.3	6.2	1.8	0.9	3.9	2.9
punctifer	646	1	46.0	34.5	54.0	17.0	12.0	6.4	6.0	1.7	1.1	4.1	3.4
intertinctus	842-977	3	46.5-48.0	35.5-36.5	52.0-53.5	16.5-17.0	11.0-12.0	5.5-6.4	5.4-6.3	1.5-1.9	0.5-0.9	4.3-4.6	3.1-3.3
mordax	940-1110	2	45.5-47.5	33.5-35.0	52.5-54.5	17.5-18.5	12.0-12.5	6.5-6.6	6.3-6.4	1.8-1.9	0.7-0.8	3.7-4.4	3.2-3.4
punctifer	890-1190	3	47.0-48.0	35.0-36.0	52.5-53.0	17.5-19.0	11.5-13.0	5.7-7.2	5.4-6.8	1.5-1.9	0.6-1.2	4.1-5.2	3.2-3.4

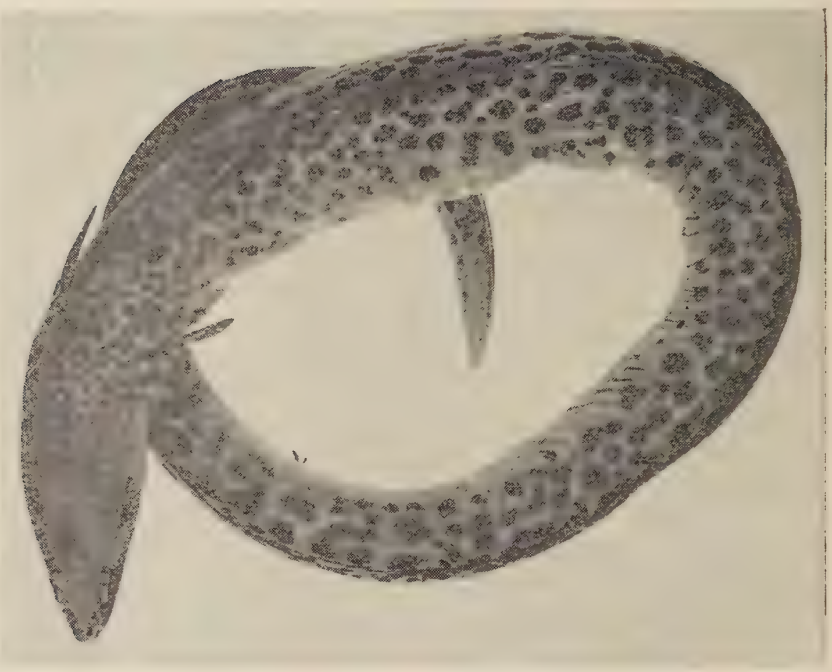

FIGURE 11.—*Mystriophis intertinctus;* U. S. N. M. 151927; 977 mm; Cape Fear, North Carolina.

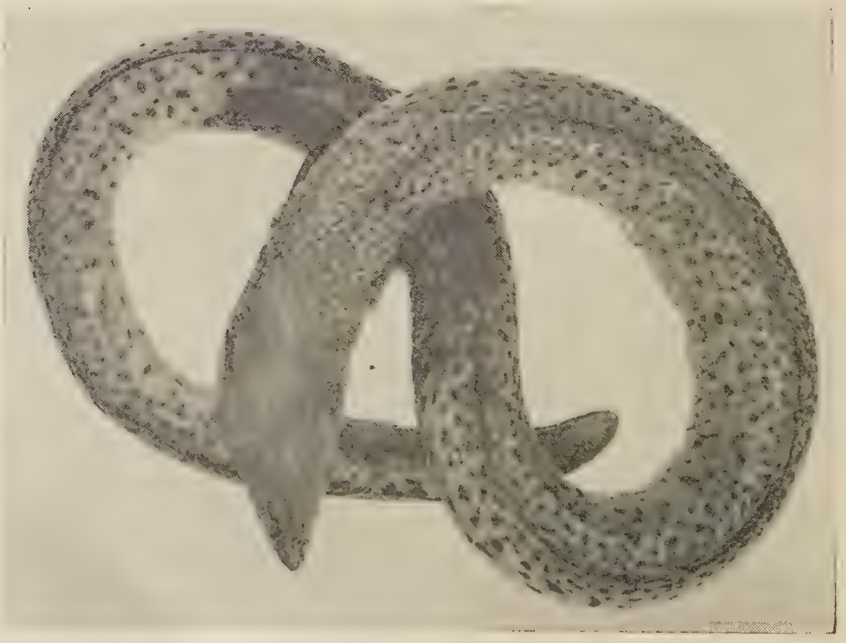

FIGURE 12.—*Mystriophis mordax;* U. S. N. M. 152990; 1110 mm; off Mississippi Delta.

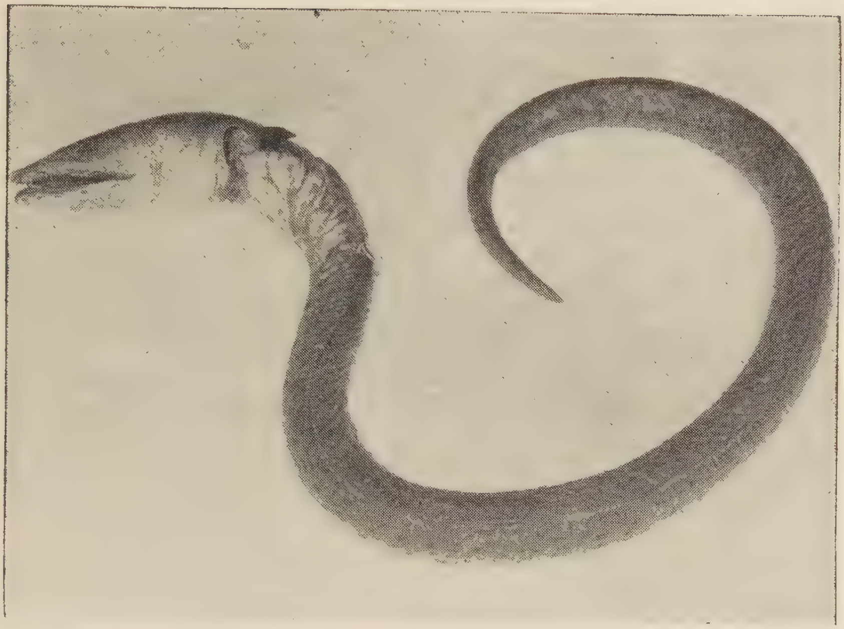

FIGURE 13.—*Mystriophis mordax;* from the type; M. C. Z. 9220; 940 mm; Cuba; specimen evidently faded in part.

In a specimen 351 mm largest spots a little smaller than snout and eye combined, roughly in 3 lengthwise rows; in specimens 428-671 mm largest spots about equalling snout, roughly in 3 lengthwise rows; in 2 specimens 940-1110 mm largest spots smaller than snout and a little larger than eye, roughly in 4 lengthwise rows; interpolated spots in all specimens, many or in moderate numbers.

Specimens examined from or off the following localities: Padre Island, Texas (154995, Pelican Station 113-8; 30 fathoms); off Mississippi Delta; 30 fathoms; Stewart Springer; 1110 mm; the largest specimen (152990); Tampa (152251) and Garden Key (5984), Florida; Cuba (M.C.Z. 9217 and 9220, the latter the type). Altogether 6 specimens 351-1110 mm.

In the size of the spots this species is in a sense intermediate between *mordax* and *intertinctus,* but distinctly nearer the latter and rather widely discontinuous with that of *mordax.* The spots are smaller and usually more widely spaced than in like-sized specimens of *intertinctus.* Specific differences in the size and spacing of the spots on the nape, as well as on the body, are well marked on direct comparison of specimens size for size. The relationship between the three species is further discussed under the account of the genus.

It is doubtful whether the specimen which is entered as the type of *mordax* in the catalog of the Museum of Comparative Zoology, is in reality the same specimen which served as the basis of Poey's description of that species. The author states: "Le corps . . . couvert de taches . . . les plus grandes ne dépassant pas cinq millimètres . . ." This statement applies well to large specimens—such as Poey described—of that species which is here designated as *punctifer;* while the largest spots in the presumed type specimen actually are about 10 mm. Assuming that this specimen is the type, it is difficult to see how Poey could have made this error in view of his categorical statement. Nevertheless, the name here applied is based on the assumption that it is the type. A minor discrepancy is in the length of the specimen. Poey gives the length of his specimen as 990 mm, whereas the specimen in the M.C.Z. measures 940 mm. However, this discrepancy may be explained as being partly due to shrinkage and partly to the difficulty of making very accurate measurements of eels which have become curled in preservative.

MYSTRIOPHIS PUNCTIFER (Kaup)

Crotalopsis punctifer Kaup, Abh. Naturw. Ver. Hamburg 4 (abt. 2): 13, pl. 1, fig. 3, 1860 (Puerto Cabello)—Springer and Allen, Copeia, 1932 (2): 105 (off Horn Island, Mississippi; specimen now bears U. S. N. M. 125911 and is the largest one included in the following account)

Ophichthys punctifer Gunther, Cat. Fish. Brit. Mus. 8: 56, 1870 (Puerto Cabello)

In a specimen 646 mm largest spots slightly smaller than snout, slightly larger than eye, an imaginary narrow transverse band crossing widest part of spotted area touching about 6 of larger spots; interpolated spots moderately smaller than large spots; in 3 specimens 890-1190 mm largest spots smaller than eye, the above imaginary band touching about 10 spots; spots variable in size but not definitely divisible into two size groups.

Specimens examined: Texas; landed by a fishing boat at Freeport, Texas, apparently captured off the coast of that state, sent in by J. L. Baughman of the Texas Game, Fish and Oyster Commission; 2 specimens 890-950 mm (152240). Off Corpus Christi Pass, Texas; Pelican Station 108-12, lat. 27° 42' 30" N, long. 96° 21' 30" W; 35 fathoms; 646 mm (154996). 12 miles off Horn Island, Mississippi; Stewart Springer; November 17, 1931; 1190 mm (125911).

This species is characterized by its small and numerous spots when compared size for size with specimens of the other two species of *Mystriophis*, as discussed under the account of the genus.

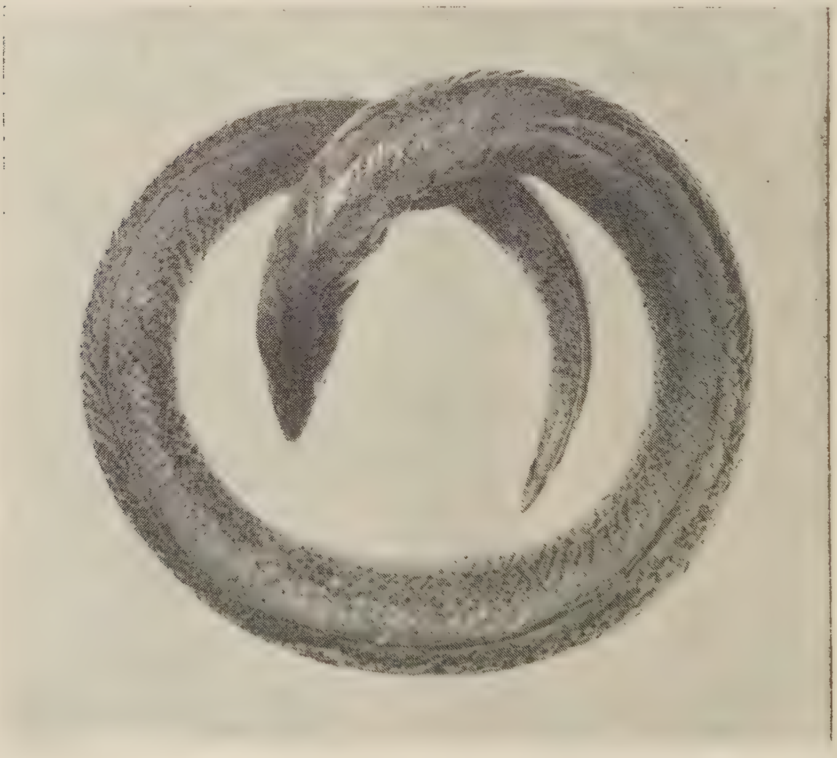

FIGURE 14.—*Mystriophis punctifer;* U. S. N. M. 125911; 1190 mm; off Horn Island, Mississippi.

OPHICHTHUS Ahl

Ophichthus Ahl, Specimen Ichthyologicum de Mureana et Ophichtho. Inaug. Dissert. Upsala, p. 6, 1789 (genotype *Muraena ophis* Linnaeus by later designation)

Ophichthys Bleeker, Atlas Ichthyologique des Indes Oriëntales Néèrlandaises 4: 36, 1864 (*Ophichthys* [sic] *ophis* Ahl=*Muraena ophis* Linnaeus designated as genotype)

Moderately deep, tapering. Tail longer than body. Eye medium, 1.3-2.0 in snout. Mouth and jaws rather large; lower jaw 2.1-3.2 in head; angle of mouth at some distance behind eye, a vertical through middle of eye bisecting lower jaw or a little nearer its tip than angle of mouth; premaxillary teeth slightly or a little exposed with the mouth closed. Snout of moderate length and taper, 4.8-6.1 in head, moderately extending beyond lower jaw. Lips hardly or very moderately differentiated, lower lip usually somewhat more so than upper. Posterior nostril placed at some distance before eye and a little above rim of gape, its size and raised rim moderate (except in *gomesii*, see its description); anterior nostril ending in a tubule, near edge of gape at a moderate distance from end of snout. Tongue adnate. Gill opening placed on lower half of side, transversely curved, moderately large, subequal to interval between the two fellows. Dorsal origin behind gill opening, differing from a short distance in front of a vertical through end of pectoral to a moderate distance behind. Dorsal and anal fins rather low or moderate, more or less modified posteriorly, a variable stretch of fin lower than parts immediately preceding and following, the rays in this stretch thicker than others (see below discussion of this structure). Pectoral comparatively rather well developed. Teeth tapering, pointed, moderate to rather large, moderately differing in size in different areas, none conspicuously larger than others to be designated canine; teeth extending over entire length of jaws; typically teeth in jaws in two rather well separated rows and in one or two rows on palate depending on the species; inner row of lower jaw often more or less incomplete in *ocellatus* and *retropinnis*; in *gomesii* teeth in jaws and on palate increasing in number with growth to form bands of teeth in large specimens; premaxillary teeth 4-8 in a single curved row, sometimes one tooth behind row in *gomesii*: groups of premaxillary, jaw and palatal teeth slightly or rather well separated from one another.

The differences between *Ophichthus* and the other genera of its family are indicated in the key. It is most nearly related to *Mystriophus* and the differences between them are discussed under that genus.

The name Ophichthus rests on uncertain grounds; because later authors failed to identify definitely *Muraena ophis* Linnaeus which has been designated by Bleeker as the genotype of *Ophichthus.*

Norman (1922, p. 296) describes a new genus and species, *Acanthenchelys spinicauda,* based on a specimen from Tobago. He also states that *Ophichthus ocellatus* LeSueur belongs to the new genus which is "distinguished by the structure of the anal fin . . . having a series of short spines not far from the end of the tail."

I made an attempt to study the variability of this character in *ocellatus* and the other species here placed in *Ophichthus* and found it very difficult of precise determination; because it is not sharply marked and depends to a large extent on the state of preservation of the specimens. Often the fins are contracted and adhere tightly to the body, or the specimens, including the fins, are too hardened by the preservative. Subject to these serious limiting factors, this structure and its variability may be described as follows.

In *ocellatus* the anal fin for a moderate and variable stretch, at a moderate distance before its end, is lower than the parts immediately preceding and following. The rays in this stretch are shorter and thicker and rather spine-like in appearance. Usually they are flexible at the tips, but sometimes moderately pungent. Often specimens seem to have this structure poorly developed or lacking, but such specimens are usually hardened by preservative and it is not possible to be certain whether the seeming lack of the structure is due to preservation. In favorably preserved specimens, the same structure is discernible also in the dorsal fin. Sometimes it is present in the dorsal and seemingly lacking in the anal or vice versa.

In the one specimen each examined of *guttifer* and *retropinnis* this structure is present both in the dorsal and anal.

In *gomesii* the same structure is discernible in the dorsal and anal in favorably preserved specimens, except that it is not as well developed as in the preceding three species, the rays are not as thick and they are more flexible. Also, the modification seems to be more often lacking than in *ocellatus.*

Because of the difficulties in the precise determination of this character, it is not used here for the practical purpose of distinguishing the genera and species.

OPHICHTHUS OCELLATUS (LeSueur)

Muraenophis ocellatus LeSueur, Jour. Acad. Nat. Sc. Philadelphia 5: 108, pl. 4, fig. 3, 1825 (South America)

Ophichthys ocellatus Gunther, Cat. Fish. Brit. Mus. 8: 68, 1870 (Mexico)

Ophichthus ocellatus Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 630, 1891 (Snapper Banks near Pensacola)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47(1): 383, pl. 64, fig. 169, 1896 (West Indian fauna, south to Brazil, north to Pensacola)—Schroeder, Copeia 1941(1): 45 (off Pensacola; *guttifer* synonymized with *ocellatus*)

Lower jaw 2.3-2.6 in head. Dorsal origin usually in front of a vertical through pectoral end, at a distance about equalling eye diameter, varying from half an eye diameter to nearly the length of the snout (in 17 specimens), often directly over pectoral end (in 6), sometimes slightly behind this vertical (half an eye diameter behind in 1). Teeth rather large; teeth in inner row of lower jaw, except for a short distance anteriorly, smaller than those in outer row and variable in number from a nearly complete row to a few; most inner teeth of upper jaw subequal in size, and also in number to outer teeth; palatal teeth in a single row extending to opposite posterior margin of eye or moderately behind, except often two small teeth, side by side, in front of anteriormost tooth, sometimes two such pairs or only one such tooth or absent altogether, anterior 2-5 teeth in main row rather large, subequal or moderately unequal, usually separated by an interval from following teeth, latter teeth smaller and decreasing in size posteriorly.

Ground color brown above, yellowish below; a row of rather large white spots, nearly median in position, along almost entire length of fish; largest spots in any one specimen usually about equalling eye diameter, the ratio of the eye divided by the spot varying 0.7-1.5; nuchal region often with a whitish, rather narrow stripe anteriorly and a few irregularly scattered spots, smaller than the median spots, posteriorly, sometimes with some other, shorter stripes or rows of small coalescent whitish spots; pores on head and lower jaw often marked by small brown spots.

Measurements of 6 specimens 393-588 mm and 2 specimens 162-293 mm: body 46-47 (43-44), trunk 33-35 (32-33), tail 53-54 (57), antedorsal 14.0-17.5 in 21 specimens 342-594 mm (14.0-14.5), head 12.0-13.5 (10-11), upper jaw 5.0-6.3 (4.1-5.0), lower jaw 4.6-5.9 (3.8-4.3), snout 2.2-2.7 (1.9-2.0), eye 1.2-1.7 (1.2), depth about 3.3-4.1, not accurately determinable in most specimens examined (3.6), pectoral 4.4-5.5 (2.7-3.6). Upper jaw in head 2.1-2.3 (2.2-2.5).

Specimens examined from or off the following localities: Mobile, Alabama; Pensacola (including those recorded by Schroeder, 10 of those specimens that were preserved; M.C.Z. 35109), Cedar Keys, Englewood, Nassau Sound, Captiva Key and Matanzas Inlet, Florida; Brunswick, Georgia; Charleston and Sullivan Island, South Carolina; Beaufort Inlet, North Carolina. Six depth records recorded for the lots examined range 5-79 fathoms. The largest specimen is 640 mm from off Matanzas Inlet.

The difference between this species, *retropinnis* and *guttifer* are discussed under the account of the latter.

OPHICHTHUS GUTTIFER Bean and Dresel

Ophichthys guttifer Bean and Dresel, Proc. Biol. Soc. Washington 2: 99, 1884 (Gulf of Mexico)

Ophichthus guttifer Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 630, 1891 (Snapper Banks near Pensacola)—Jordan and Evermann, Bull. U. S. Nat. Mus. 46(1): 383, pl. 64, fig. 168, 1896 (Snapper Banks off Pensacola)

Lower jaw 2.1 in head. Dorsal origin behind a vertical through pectoral end, at a distance nearly equalling length of snout. Teeth rather large; inner teeth in lower jaw, except for a short distance anteriorly, smaller than those in outer row, and fewer in number, more widely spaced; teeth in both rows of upper jaw subequal in size and number; palatal teeth in a single median row divided into two parts by a short interval, anterior part in front of eye level consisting of 4 teeth, increasing moderately in size posteriorly, posterior part longer, ending on a vertical at some distance behind eye, the teeth decreasing in size posteriorly.

Light brown above, yellowish below; a lengthwise, nearly median series of white spots from head to within a short distance from posterior end, largest of white spots approximately 2 times in eye; nuchal region with a transverse row of very small whitish spots anteriorly, and some shorter lengthwise rows in front of it, and with a few small, irregularly scattered, whitish spots posteriorly.

Measurements of type specimen: total length 572 mm, body 46, trunk 33, tail 54, antedorsal 19, head 13, upper jaw 6.5, lower jaw 6.1, snout 2.5, eye 1.4, depth 3.8, pectoral 4. Upper jaw in head 2.

Specimen examined: sent by Silas Stearns from Pensacola, Florida, without further data, probably captured by a fishing boat in the Gulf of Mexico, the type of species (32647).

Three species of *Ophichthus* occurring in the Gulf, *ocellatus, guttifer* and *retropinnis*, agree in having a median series of white spots, and nearly agree in the dentition, in the relative length of the body and tail and most other measurements. The differences between them are here conveniently discussed together.

The chief difference is in the relative position of the dorsal origin. In 24 specimens of *ocellatus* examined, 23 have the dorsal origin on a vertical through the end of pectoral or a variable and short distance in front of this vertical, varying to a snout length in front as a maximum. In only one specimen of the 24, the dorsal originates slightly behind this vertical, at a distance about equalling half an eye diameter. In the single known specimen of *retropinnis* the dorsal origin is at a distance behind that vertical equalling a little over three snout lengths. Although *retropinnis* was not rediscovered since it was described more than 60 years ago, it is evidently a valid species. The size of the white spots in *retropinnis* is about as in *ocellatus*.

The dorsal origin in the single type specimen of *guttifer* is rather intermediate between the above two species, but nearer to *ocellatus*. It is behind the vertical indicated above, at a distance slightly less than the length of the snout or about equalling 1½ times the eye. The type of *guttifer* thus differs appreciably from the 24 specimens of *ocellatus* examined. Another difference is in the size of the white spots which are appreciably smaller in the type of *guttifer*. The size of the white spots in *ocellatus* varies with the individual and also in different parts of the body of the same specimen. The size of the largest spots in the 24 specimens of *ocellatus* examined varies from a little larger than the eye to slightly more than 2/3 the eye diameter as a minimum, while in *guttifer* the largest spots are ½ the eye diameter. The relative size of the spots in the two species is fairly indicated in the two figures published by Jordan and Evermann (above citation).

From the above comparison of the type of *guttifer* with a fair sample of *ocellatus*, 24 specimens from a considerable geographic range of the species, I draw the following conclusion. There is some possibility that the type of *guttifer* is an extreme variant of *ocellatus*. However, in that case it would be necessary to assume that it is an extreme variant in two characters. Considering the evidence, it is more likely that it represents a valid species. Furthermore, in order to solve the entire problem satisfactorily it is necessary to determine the intraspecific variability in the position of the dorsal origin and the size of the spots in *retropinnis* also. Since the position of the dorsal origin in the type of *guttifer* is to a certain extent intermediate between that in *ocellatus* and *retropinnis*, there is also a remote possibility that *guttifer* is based on an example of *retropinnis*. Consequently, from a practical viewpoint it seems best to recognize tentatively all three species as distinct. Very likely this will prove to be correct after an examination of adequate samples when they become available.

Differences in the position of the dorsal origin between the three species are also shown by the relative length of the antedorsal distance; 14.0-17.5 per cent of the length in 23 specimens of *ocellatus*; 19.0 and 23.5 in the types of *guttifer* and *retropinnis*, respectively.

OPHICHTHUS RETROPINNIS Eigenmann

Ophichthys retropinnis Eigenmann, Proc. U. S. Nat. Mus. 10: 116, 1888 (Pensacola, Florida; taken from the stomach of a fish)

Ophichthus retropinnis Jordan and Davis, Rep. U. S. Comm. Fish 1888: 630, 1891 (based on same specimen)—Jordan and Evermann, Bull. U. S. Nat. Mus. 46(1): 383, 1896 (Snapper Banks off Pensacola)

Lower jaw 2.4 in head. Dorsal origin behind a vertical through pectoral end at a distance a little more than three snout lengths, nearly equal to postorbital part of head. Teeth rather large, inner row of lower jaw incomplete and the teeth notably smaller than in outer row; in upper jaw both rows complete and the teeth subequal; palatal teeth virtually in a single row extending to a vertical a little behind eye, the teeth decreasing in size posteriorly, a short interval between third tooth in row and the following teeth, two teeth side by side, one on either side of midline, at some distance in front of and smaller than first tooth in median row.

The specimen examined, taken from the stomach of a fish, is in an early stage of digestion. The skin on the left side is nearly all gone, but on the right side enough is left to show a number of the white median spots the largest of which are subequal to the eye.

Measurements of type specimen: length 523 mm, body 47, trunk 35, tail 53, antedorsal 23.5, head 12, upper jaw 5.2, lower jaw 4.9, snout 2.2, eye 1.5, depth 3.2, pectoral 5.1. Upper jaw in head 2.3.

Specimen examined: the type (38054), "taken from the stomach of some other fish" and "sent in by Mr. Silas Stearns," presumably taken by a fishing boat off Pensacola, Florida.

The differences between this species, *ocellatus* and *guttifer* are discussed above under the account of the latter.

OPHICHTHUS GOMESII (Castelnau)

Ophisurus gomesii Castelnau, Animaux nouveaux ou rares l'Amerique du Sud, p. 84, pl. 44, fig. 2, 1855 (Rio de Janeiro)

Ophichthys gomesii Gunther, Cat. Fish. Brit. Mus. 8: 60, 1870 (after Castelnau)

Ophichthus gomesii Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 632, 1891 (Charleston to Rio Janeiro)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47 (1): 384, 1896 (South Carolina to Rio de Janeiro)

Lower jaw 2.8-3.2 in head. Posterior nostril notably large, its rim well developed, placed on edge of gape under anterior margin of eye. Dorsal origin varying from a point over pectoral end to a point more forward about equalling snout. Teeth moderate, arch of premaxillary row often curving sharply at symphysis resulting in a V shaped row, sometimes having gross effect of two nearly parallel, approximated rows at anterior end of upper jaw, sometimes one tooth not aligned in the row, placed on area bounded by arch; in medium sized specimens, 320-420 mm, in two rows in jaws, inner teeth slightly smaller than outer; in such specimens palatal teeth in two moderately or well separated rows anteriorly, converging posteriorly and becoming a single irregular row for a short distance at its posterior end, the palatal teeth moderately decreasing in size posteriorly and extending to a point about opposite angle of mouth; with growth, maxillary, palatal and mandibular teeth increasing in number, the bands of teeth in 4 irregular somewhat incomplete rows at about 600 mm; in 2 specimens 211-238 mm teeth in jaws in 2 rows as previously stated for the medium sized specimens, but outer row of mandibular teeth incomplete posteriorly. Yellowish or brownish, darker above. lighter below, dorsal and anal edged with black for their greater part or only posteriorly, no distinctive markings.

Measurements of 18 specimens 319-609 mm and 2 specimens 211-238 mm: body 36-38 (33-34), tail 62-64 (66-67), trunk 25-27 (22-24), antedorsal 13.0-15.5 (13), head 10.0-12.0 (10.5-11.5), upper jaw 3.7-4.5 (4.2), lower jaw 3.3-4.2 (3.5-3.7), snout 1.9-2.4 (1.8-1.9), eye 1.0-1.4 (1.2-1.4), depth 4.0-5.1 (3.6-4.2), pectoral 3.6-5.1 (4.2-4.5). Upper jaw in head 2.5-2.8 (2.5-2.7).

Specimens examined from the following localities: Charleston, South Carolina; Cape Canaveral, Key West, Gulf Port, Apalachicola, Cape San Blas, and Pensacola, Florida; Bayou La Batre, Alabama; Mississippi Sound; Bayou St. Denis and Grand Isle, Louisiana; Freeport, Port Aransas and Padre Island, Texas; Puerto Rico; Rio de Janeiro. Only one depth record, 13 fathoms, is available for the lots examined. Most other specimens were apparently taken in shallow water. The largest specimen is 609 mm, taken in Bayou St. Denis.

This species is easily distinguishable from the other three species of its genus here treated by its notably longer tail, the shorter trunk, the presence of 2-4 rows of palatal teeth, the position of the posterior nostril and the absence of white spots.

In the size of the mouth and the strength of the jaws, this species is somewhat intermediate between the two major groups of genera, not counting *Verma*, distinguished in the key. In the relative length of the tail it diverges notably from both groups. In the position and structure of the posterior nostril it nearly agrees with the second group. On a constructive revision of the family it might be found desirable to place *gomesii* in a genus distinct from that of the three other species here placed in *Ophichthus*.

BASCANICHTHYS Jordan and Davis

Bascanichthys Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 621, 1891 (genotype *Caecula bascanium* Jordan by original designation)

Very slender, depth 1.1-2.6; subterete to moderately compressed, or subtriangular in cross-section. Tail a little shorter than body. Eye small, 1.8-3.6 in short snout. Mouth and jaws small; lower jaw 4.3-6.7 in head; angle of mouth behind eye, a vertical through middle of eye about bisecting lower jaw, varying a little both ways; premaxillary teeth a little exposed with the mouth closed. Snout short, 5.9-7.9 times in head; subconical; well projecting beyond lower jaw. Upper lip not differentiated;

lower lip separated by a slight groove at angle of mouth. Posterior nostril notably large, placed on rim of gape under anterior half of eye, its outer half with a broad, flaring, raised margin, inner half without raised margin; anterior nostril a broad, bulging, low tubule, placed at edge of gape directly in front of lower jaw. Tongue virtually adnate, its rim slightly projecting. Gill opening placed on lower half of side, transversely rounded, of moderate extent, subequalling space between the two fellows. Dorsal origin on head, a short distance behind a vertical through angle of mouth; dorsal and anal low or moderate. Pectoral very small; in medium sized specimens subtriangular and its length about equalling eye diameter, becoming rather broad and slightly longer in large fish. Teeth pointed, only moderately differing in size in different areas; no canines; teeth in lower jaw extending over its whole length; teeth in upper jaw beginning before eye and ending a short distance from angle of mouth; jaw teeth typically in one row, often an incomplete second row in upper jaw varying from one to a few teeth in the larger specimens, infrequently a second row in small part in anterior portion of lower jaw; palatal teeth in two rows anteriorly tapering to one row or one tooth on midline posteriorly, ending more or less before a vertical through angle of mouth; premaxillary teeth usually 3, disposed as the apices of an imaginary triangle, varying 2-4; premaxillary and anterior palatal teeth subequal and moderately larger than all others.

The preceding description of the dentition is based on the specimens examined of *teres* and *scuticaris*, with the exception of one large specimen of *scuticaris* in which the teeth, especially the premaxillary teeth, are in greatly increased numbers as described under its species.

Ground color brownish or yellowish, variable, light to dark; upper half darker than lower; a longitudinal, nearly median row of whitish spots, along nearly entire length of fish, curving upward in front of gill opening, the spots sharply marked or faint, often absent, each spot directly over a pore; dorsal and anal usually lighter colored than body. Both species have the same variable color pattern.

BASCANICHTHYS TERES (Goode and Bean)

Sphagebranchus teres Goode and Bean, Proc. U. S. Nat. Mus. 5: 436, 1882 (West Florida)

Caecula bascanium Jordan, Proc. Acad. Nat. Sci. Philadelphia 36: 43, 1885 (Egmont Key, Florida)

Bascanichthys bascanium Jordan and Davis, Rep. U. S. Comm. Fish 1888: 621, 1891 (based on type)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47 (1): 379, 1896 (based on type)

The number of teeth not showing a definite change with growth in 8 specimens 351-798 mm examined: teeth in upper jaw in one row, except a second row in small part consisting of 1-2 teeth in 3 specimens 419-525 mm; in all specimens one row in lower jaw, on palate 2 rows anteriorly tapering to one row posteriorly, 2-3 premaxillary teeth.

Measurement of 5 specimens 486-798 mm: body 53-55, trunk 47-50, tail 45-47, antedorsal 2.1-3.1, eye 0.3-0.5 and 1.8-2.6 times in snout. In 8 specimens 351-798 mm: head 4.1-6.5, depth 1.7-2.6, upper jaw 1.1-1.8, lower jaw 0.9-1.2, snout 0.6-1.0. Depth 2.2-3.1 times in head; upper jaw in depth 1.2-1.8, lower jaw in depth 1.6-2.2, snout in depth 2.1-3.1. Snout 5.9-7.9, and lower jaw 4.6-6.7 times in head.

Specimen examined from Corpus Christi, Texas; Mississippi coast; Lemon Bay, Florida; also the type specimens from "West Florida." The largest specimen is from Corpus Christi.

LECTOTYPE.—U. S. N. M. 31457. The type jar contains 3 specimens, one of them stouter than the other two and its depth falls near the center of the range of variation of *teres*; the others approach the distribution of *scuticaris*. As the two species approach closely in their distinguishing characters, it seems best to designate a lectotype, and the deeper specimen, 525 mm long, is so designated.

The differences between this species and *B. scuticaris* are discussed under the account of the latter.

SYNONYMY.—The type of *bascanium* was not examined. (The type specimen appears to have been lost; see Storey 1939, p. 75.) That name is placed in synonymy on the basis of the original description. Jordan states that *bascanium* differs from *scuticaris* and *teres* "by the shorter head and better developed pectoral fin." The head in the type of *bascanium* was 4.5 per cent of the total length, which falls within the range of variation of *teres*. The size of the pectoral increases in large specimens of both *teres* and *scuticaris*, and the size of the type of *bascanium*, 31 inches, is near the maximum attained by either species, which accounts for the "better developed pectoral." The depth of the type specimen, 2.5 times in head, is near the center of the range of variation of *teres* and outside that of *scuticaris.*

BASCANICHTHYS SCUTICARIS (Goode and Bean)

Sphagebranchus scuticaris Goode and Bean, Proc. U. S. Nat. Mus. 2: 343, 1880 (Cedar Key, Florida)

Bascanichthys scuticaris Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 621, 1891 (Pensacola, Punta Rassa and Egmont Key, Florida)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47(1): 378, pl. 63, fig. 165, 1896 (West coast of Florida)

The number of teeth increasing with growth. In upper jaw teeth in a single row in 2 specimens 260-370 mm; in 11 specimens 464-623 mm in a single row or partly in 2 rows depending on the individual, in one row in the largest of these, in 2 rows in small part in smallest. In lower jaw in one row in all the above 13 specimens, except in 2 rows in small part anteriorly in one specimen 568 mm. In same 13 specimens, palatal teeth in 2 rows anteriorly tapering to a single row or to one tooth on midline posteriorly, and premaxillary teeth usually 3, varying 2-4. In the largest specimen (755 mm, the type), in upper jaw in 2 rows and partly in 3 rows, in lower jaw in 2 rows in large part, on palate in 3 irregular rows anteriorly tapering to 1 tooth on midline; premaxillary teeth in greatly increased numbers, 10 altogether, irregularly arranged.

Measurement of 6 specimens 531-755 mm: body 53-55, trunk 48-50, tail 45-47, antedorsal 2.0-3.5, eye 0.3-0.5 and 2.0-3.6 times in snout. In 13 specimens 260-755 mm: Head 4.8-6.5, depth 1.1-1.6, upper jaw 1.3-1.9, lower jaw 0.9-1.5, snout 0.7-1.1. Depth in head 3.4-5.4 times, upper jaw in depth 0.7-1.0, lower jaw in depth 0.9-1.6, snout in depth 1.1-2.0. Snout 5.9-6.9 and lower jaw 4.3-5.7 times in head.

Specimens examined from Aransas Bay, Texas; Pensacola, Cedar Keys (the type, 23636) and Lemon Bay, Florida; off Cape Hatteras, North Carolina. The latter specimen taken by the Pelican at 11 fathoms; no depth record available for the others. The largest specimen is the type, 755 mm.

This species differs from *B. teres* chiefly in proportional measurements, the most conspicuous of which is the body depth, *scuticaris* being more slender. Most specimens are distinguishable on sight by this difference when compared size for size. Others, at a glance, appear to be intermediate in body depth. But determination of the proportional depth measurements of all available specimens shows no intergradation between the two species although they closely approach in this character. Furthermore, *scuticaris,* while having a more slender body, averages a longer head, upper and lower jaw, and snout. Therefore, the ratios of these four measurements as compared with the depth measurement, are given under both species, in the same order, for the purpose of comparison. This should help to place specimens which are near the borderline with respect to depth measurement.

CALLECHELYS Kaup

Callechelys Kaup, Cat. Apod. Fish. Brit. Mus., p. 28, 1856 (genotype *Callechelys guichenoti* Kaup by monotypy)

This genus, judged by the one species studied, *C. muraena,* is nearest to *Letharchus.* Both genera about agree in the position, direction and shape of the gill opening, the short row of teeth in the upper jaw, the rather high dorsal fin, the short tail and the absence of pectorals. *Callechelys* differs in having an anal fin. The generic characters are included below in the description of the single Gulf species examined. Another species previously described from the Gulf from a single specimen which was not examined is discussed below.

CALLECHELYS MURAENA Jordan and Evermann

Callechelys muraena Jordan and Evermann, Proc. U. S. Nat. Mus. 9: 466, 1886 (Snapper Banks between Pensacola and Tampa Bay)—Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 620, pl. 87, 1891 (based on type)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47: 378, pl. 63, fig. 164, 1896 (based on type)

Compressed, moderately slender. Tail shorter than trunk. Eye small, 1.8-2.0 times in short snout. Mouth and jaws small; lower jaw 4.2-4.3 times in head; angle of mouth at a considerable distance behind eye, a vertical through posterior margin of eye nearer tip of lower jaw than angle of mouth; premaxillary teeth exposed with the mouth closed. Snout short, 7.0-8.5 times in head, its dorsal aspect rounded, notably overhanging the short lower jaw. Lips slightly differentiated near angle of mouth. Posterior nostril notably large, placed on rim of gape under anterior margin of eye, its anterior rim well developed and flaring, its posterior rim moderately so; anterior nostril ending in a rather well developed tubule, placed on lateral profile, somewhat nearer end of snout than posterior nostril. Tongue adnate. Gill opening placed low, its entire outline visible on ventral as well as on lateral aspect, placed horizontally in large part, curving downward in front, the space between the two fellows smaller than opening. Dorsal and anal fins rather well developed, dorsal beginning on head not far behind angle of mouth; no pectoral fin. Teeth medium, moderately differing in size; in one row in jaws; row in upper jaw short, beginning at posterior nostril and ending at some distance before angle of mouth, the teeth small; row in lower jaw beginning at symphysis and ending at angle of mouth, the teeth rather large anteriorly decreasing in size posteriorly; palatal teeth in two rows anteriorly one row posteriorly, anterior teeth comparatively large, 3 in each row, teeth in posterior row 3-4, smaller; premaxillary teeth 3, the anterior one on midline, the other two side by side, behind and close to anterior tooth, the teeth about as large as the anterior palatal teeth. Ground color yellowish, rather thickly spotted or clouded with rather small, diffuse, brown spots.

Measurements of 2 specimens 329-584 mm: body 60-61, trunk 52, tail 39-40, antedorsal 2.8-3.2, head 8.1-8.4, upper jaw 2.3-2.6, lower jaw 1.9-2.0, snout 1.0-1.2, eye 0.5-0.6, depth 2.4-3.0

Two small specimens, 84-167 mm, have the upper jaw and palatal teeth somewhat more numerous and the rows a little longer. Proportional measurements also differ moderately from the larger specimens, as follows: Body 55-56, trunk 47-49, tail 44-45.

Specimens examined all from the west coast of Florida: Snapper banks between Pensacola and Tampa Bay (37996, the type 329 mm). Pensacola Harbor (44651, 584 mm). Clearwater Harbor (39652, 167 mm). Marco (152252, 84 mm).

This species is readily distinguished from other Gulf ophichthids, except *C. perryae*. by the combination of its generic and specific characters. Its relationship is discussed above under the genus.

Storey (1939, p. 71) describes a new species, *Callechelys perryae,* based on a specimen, 734 mm, taken off Sanibel Island, Florida. Converting the author's given figures to percentages of the total length to make them comparable with the method of description used in this paper, the proportional measurements of her type specimen are: trunk 61, tail 33, antedorsal 2.5, head 6.7, snout 0.9 and eye 0.3. This specimen then has a notably longer trunk and shorter tail than the 4 smaller specimens included in the above account.

LETHARCHUS Goode and Bean

Letharchus Goode and Bean, Proc. U. S. Nat. Mus. 5: 436, 1882 (genotype *Letharchus velifer* Goode and Bean by monotypy)

This genus is readily distinguished from the other ophichthid genera in the Gulf by the presence of a well developed dorsal fin in combination with the absence of anal and pectoral fins. Other notable characters are the absence of premaxillary teeth and the relatively short tail. The non-tubular anterior nostrils constitute a good distinguishing character. The generic characters are included below under the description of the single species known from the Gulf. This genus is structurally nearest *Callechelys* as discussed under that genus.

LETHARCHUS VELIFER Goode and Bean

Letharchus velifer Goode and Bean, Proc. U. S. Nat. Mus. 5: 437, 1882 (West Florida)—Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 616, 1891 (Pensacola)—Jordan and Evermann, Bull. U. S. Nat. Mus. 47: 375, pl. 61, fig. 160, 1896 (Snapper Banks off Pensacola and Tampa)

Compressed, depth medium. Tail shorter than trunk, moderately tapering for a short distance posteriorly. Eye very small, 1.7-2.2 in the very short snout. Mouth and jaws small; lower jaw 5.3-6.6 in head; angle of mouth behind eye, a vertical through posterior margin of eye nearer end of lower jaw than angle of mouth. Snout very short, 9.4-10.9 in head, notably produced beyond lower jaw, its dorsal aspect rounded. Lips differentiated posteriorly by a moderate groove extending forward to under eye. Posterior nostril large, placed on ventral aspect of lip under anterior part of eye, anteriorly with a wide, flaring, soft margin, posteriorly with hardly any raised margin; anterior nostril without a raised rim, its margin irregularly scalloped, placed on ventral aspect of snout, near lateral profile and at a moderate distance from its tip. Tongue adnate. Gill opening low, its entire outline entering ventral aspect, nearly lengthwise in position, the two fellows diverging only slightly backward, the space between them at their anterior end much narrower than the opening. Dorsal fin present, rather high (for an ophichthid), beginning on head at a short distance behind angle of mouth. Anal and pectoral fins absent. Teeth medium, moderately differing in size, no canines; teeth usually in one row in jaws; row in upper jaw short, beginning near posterior nostril and ending at some distance before angle of mouth; row in lower jaw about reaching angle of mouth or nearly so; extent of palatal teeth moderate, ending at a short distance behind eye, in two rows anteriorly, usually in one row posteriorly;

sometimes teeth in upper jaw in two rows or palatal teeth 2-rowed all the way; anterior palatal teeth somewhat larger than others; premaxillary teeth absent. Almost uniformly brown of variable shades of intensity, except lower part of head somewhat lighter, without distinctive color marks; dorsal fin in contrast light colored with a dark margin.

Measurements of 5 specimens 311-454 mm: body 59-62, trunk 51-54, tail 39-41, antedorsal 2.7-3.0, head 7.6-8.0, upper jaw 1.7-2.0, lower jaw 1.2-1.5, snout 0.7-0.9, eye 0.3-0.5, depth 2.2-3.0.

Specimens examined: West Florida (31458, the types) and Gulf of Mexico (43571), without any more definite locality. Pensacola, Florida, (44868). Pensacola Harbor (44650, 44659, 44661). Off Deadmans Bay, Florida, 10 fathoms, 60 mm (131944). Total number of specimens 26, 48-488 mm.

The striking distinguishing characters of this species, as compared with other Gulf eels are stated under the genus heading.

CRYPTOPTERYGIUM, new genus

Genotype.—*Cryptopterygium holochroma*, new species.

This genus is apparently near *Callechelys*, differing chiefly in that the dorsal and anal fins are hidden under the skin. Other generic characters are included below in the description of the genotype.

CRYPTOPTERYGIUM HOLOCHROMA, new species

The single specimen on which this species is based came to me dissected in small part. Possibly it was also mutilated in part while being captured. As a consequence, the presence or absence of pectoral fins, the precise shape of the gill opening and the structure of the tongue are not definitely determinable. Also, a small part from the ventral aspect has been cut away and

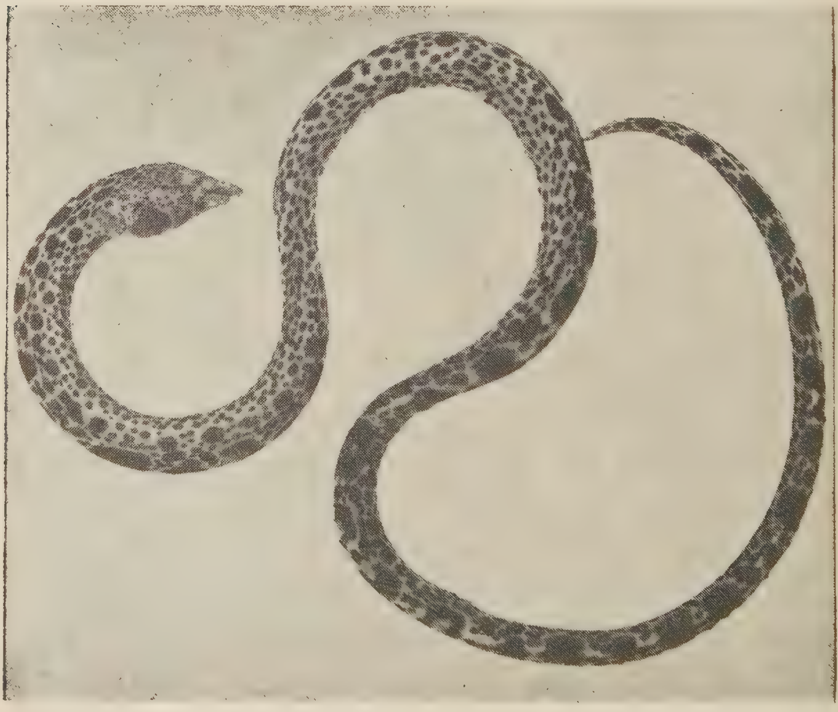

FIGURE 15.—*Cryptopterygium holochroma;* from the holotype; U. S. N. M. 154994; 801 mm; off Cape Fear, North Carolina.

the precise position of the anus is unknown. Therefore, the determined relative length of the body and tail, and also that of the head and trunk, on account of the injury to the gill opening, might be somewhat off. However, I am confident that any such error is slight. Otherwise, the specimen is in good condition and its essential characters and relationship readily determinable. Its striking color pattern should result in the identification of the species when rediscovered, without difficulty.

Slender, moderately compressed. Tail about one half as long as body, well tapering. Eye very small, 2.9 times in snout. Mouth and jaws small; lower jaw 5.2 in head; angle of mouth at a considerable distance behind eye, a vertical through posterior margin of eye nearer tip of lower jaw than angle of mouth; premaxillary teeth exposed with the mouth closed. Snout moderate, 6.9 in head, well projecting beyond lower jaw. Lips not differentiated. Posterior nostril large, placed on edge of gape under anterior part of eye, with a raised, thin, flaring rim, well developed anteriorly, moderate posteriorly; anterior nostril in a tubule placed on ventral aspect of snout, a short distance behind its end, at the lateral profile. (Gill opening placed low, oblique, of moderate size, a little larger than space between the two fellows; gill openings partly destroyed and given description tentative.) Dorsal and anal rays rather well developed but hidden under the skin, the fins visible externally as a slight mid-dorsal and ventral ridge. Teeth slender, pointed; no canines; teeth in upper jaw small in a very short row (4 on one side 6 on the other), beginning near posterior nostril and ending far from angle of mouth; teeth in lower jaw considerably larger, in one row extending nearly entire length of jaw; palatal teeth still larger, in two rows somewhat diverging backward, 3 in each row and one on midline behind and between the two rows; premaxillary teeth two, side by side, about as large as palatal teeth; upper jaw, palatal and premaxillary teeth widely spaced.

Ground color whitish, with a yellowish tinge in places; thickly covered all over, including ventral aspect, with black spots; a row of large spots saddled on back, roughly quadrangular but their boundaries irregular, unequal in size, spaced irregularly, sometimes two coalescent, in general growing smaller posteriorly; a similar row of spots on ventral aspect of tail; a very irregular row of smaller, rounded spots below the large spots on trunk; still smaller spots, of variable size, rather thickly and irregularly scattered all over, including the ventral aspect and the spaces between the larger spots described; spots on head distinctly smaller than those on body and tail.

Measurements of type specimen: total 801 mm, body 67, trunk 61, tail 33, antedorsal 2.1, head 5.7, upper jaw 1.7, lower jaw 1.1, snout 0.8, eye 0.3, depth 1.7.

HOLOTYPE.—U. S. N.M. 154994; Pelican Station 183-9; lat. 33° 30′ N, long. 78° 13′ 30″ W; off Cape Fear, North Carolina; 12 fathoms; trawl.

This species is easily recognized by its having the dorsal and anal fins covered by skin and visible externally as a slight ridge, and by its profusely, all over, spotted color pattern, including the ventral aspect.

GORDIICHTHYS Jordan and Davis

Gordiichthys Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 644, 1891 (genotype *Gordiichthys irretitus* Jordan and Davis by original designation)

The genotype of *Gordiichthys* was based on a single mutilated specimen (see below), and the genus placed in the family Muraenesocidae. I now examined another specimen in a better state of preservation which is an ophichthid and is described hereafter as *Gordiichthys springeri*. This latter specimen has the same pattern of dentition as *G. irretitus*, although it differs in detail. The two species also nearly agree in the shape of the head, the extreme slenderness, the extent of development of the dorsal fin, and the relative length of the body and tail. Therefore, I conclude that the two species are near in relationship and belong to the same genus, perhaps to two closely related genera. From this it further follows that *Gordiichthys* is more properly placed in the Ophichthidae.

GORDIICHTHYS IRRETITUS Jordan and Davis

Gordiichthys irretitus Jordan and Davis, Rep. U. S. Comm. Fish. 1888: 644, 1891 ("from the spewings of snappers . . . on the Snapper Banks at Pensacola")

This species is known only from the type, a specimen in an advanced state of digestion taken from the stomach of a fish. The type consists of two separate parts which appear to belong to the same specimen; but even this is not altogether certain. The lower part of the trunk, and an undetermined posterior part of the fish, probably a short part, are altogether missing. The skin is gone and the structure and position of the nostrils and gill opening are indeterminable, and the presence or absence of a pectoral fin is not definitely determinable. Assuming that the two parts belong to the same fish and that only a small posterior part is missing, the following very roughly approximate measurements have been determined. Total length 755 mm. Body 64, tail 36, antedorsal 2.7, depth 0.9.

Mouth small; snout tapering, well overhanging the lower jaw, premaxillary teeth exposed. Teeth variably stout more or less recurved, short or of moderate length, comparatively few in number, in one row in jaws and on palate; teeth in upper jaw 9 on right side 6 on left, moderate as compared with the largest teeth, decreasing in size posteriorly, the row beginning under eye and ending at some distance from angle of mouth; anterior 3 or 4 (differ on the two sides) in lower jaw large and very stout, gradually decreasing in size posteriorly (a small tooth at symphysis in front of anteriormost and largest tooth on left side only), these followed by 5 or 6 abruptly smaller teeth but also gradually decreasing in size posteriorly, the row extending nearly from symphysis to angle of mouth; anterior 4 palatal teeth large and very stout (the second tooth short but also stout in specimen examined), followed by 6 abruptly smaller teeth, the row extending to opposite angle of mouth; premaxillary teeth 3 closely approximated, 2 side by side and one in front bridging the space between them, somewhat stouter and larger than any of the other teeth.

This species is compared with **G. springeri** under the account of the latter. While the single known type specimen is in a bad state of preservation, the characters of the species are so well marked, as compared with other known Gulf eels, that there should be no difficulty in identifying specimens when the species is rediscovered.

GORDIICHTHYS SPRINGERI, new species

Very elongate, depth 1.3 per cent, compressed anteriorly, rounded posteriorly. Tail shorter than trunk. Eye small, 2.1 times in short snout. Mouth and jaws small; lower jaw 5.1 in head; angle of mouth at some distance behind eye, a vertical though posterior margin of eye somewhat nearer tip of lower jaw than angle of mouth; premaxillary teeth exposed with the mouth closed. Snout short, 7.7 in head, notably extending beyond short lower jaw. Lips probably not differentiated (not well preserved). Posterior nostril on ventral aspect of lip, under anterior part of eye. (Anterior nostril largely destroyed, probably in a short tubule at a short distance from end of snout.) Tongue free. Gill openings placed low, nearly horizontal posteriorly, curving downward anteriorly, the space between the two fellows

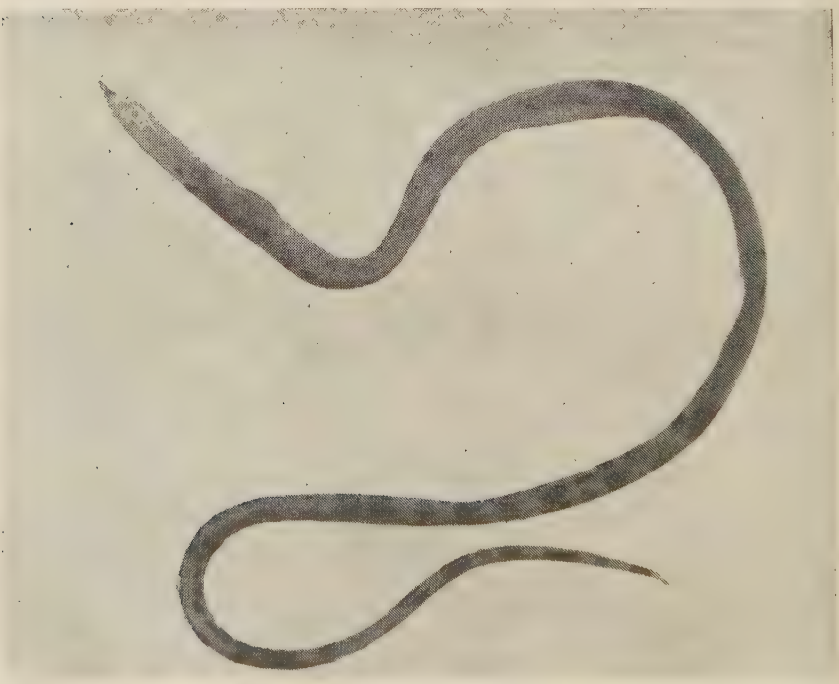

FIGURE 16.—*Gordiichthys springeri;* from the holotype; U. S. N. M. 121604; 372 mm; off Salerno, Florida.

narrow, less than diameter of small eye. Dorsal origin at a short distance behind a vertical through angle of mouth; dorsal and anal rays rather well developed (the skin binding and covering the rays largely missing). Pectorals absent. Teeth small and medium, depending on their position, recurved; upper jaw with a short row of 5 small teeth, beginning under posterior part of eye and ending at some distance before angle of mouth; lower jaw with one row of teeth (10 on right side, 5 on left, some apparently missing on that side), extending from its anterior end to within a moderate distance of angle of mouth, the first tooth small, the second notably larger, decreasing in size posteriorly; palate with a group of 5 teeth, 4 larger than lower jaw teeth, roughly arranged in 2 closely proximate rows, the fifth tooth smaller on median line, between and at front of two rows, no other teeth on palate; premaxillary teeth 3, about as large as palatal teeth, closely approximated, 2 side by side and one in front and between them (latter tooth mising in specimen examined, but scar left by it faintly evident). Ground color a light yellowish; with large brown spots, subequal to length of snout, varying moderately both ways, the spots irregularly arranged, very roughly in two very irregular rows. The color pattern is preserved in about the posterior half of the fish. Anteriorly the skin is largely digested; but some small patches of skin which are still partly preserved show traces of the brown spots.

Measurements of type specimen: body 65, trunk 58, tail 35, antedorsal 2.2, head 6.4, upper jaw 1.8, lower jaw 1.3, snout 0.8, eye 0.4, depth 1.3.

HOLOTYPE.–U. S. N. M. 121604. From stomach of **Carcharhinus milberti** taken off Salerno, Florida; in 18 fathoms; July 1-3, 1943; Stewart Springer; 372 mm.

This species is evidently nearest *Gordiichthys irretitus.* The two species seem to nearly agree in some important proportional measurements and in the size of the mouth, jaws, snout and eye. The general character of the dentition is similar in both species. However, because of the state of preservation of the two available specimens, especially the bad state of preservation of *irretitus*, no detailed comparison can now be made between the two species, except to note a well marked difference in the dentition on the palate. In *irretitus* the palatal teeth are in a single rather long row, the anterior four large, followed by 6 smaller teeth. In *springeri* the palatal teeth are 4 large ones (and a fifth smaller tooth) in 2 irregular rows and without any smaller teeth behind. This difference might prove to be of generic value when specimens in a good state of preservation are compared. The large teeth in *irretitus* are also notably stouter than in *springeri.*

The species is named after Mr. Springer who obtained the type specimen from the stomach of a shark.

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CORRECTION

In the account of **Prionotus punctatus** in this Journal, vol. 2 no. 4, p. 513, 1950, five specimens are correctly listed from Uruguay. However, in discussing some special features of these specimens the word "Paraguay" has been erroneously substituted for "Uruguay" in 4 places on the same page.

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orsal rays 109-114. Anal rays 92-98.

12a. Caudal rays usually 10, sometimes 9. Scales 102-118. No teeth on eyed side of lower jaw *jenynsi* (p. 200).

12b. Caudal rays 14. Scales 123-128. Teeth on eyed side of lower jaw present *nebulosus* (p. 200).

Symphurus minor, new species.

scription. C 10 (11). D 72-75. A 56-61.
-66. Teeth on eyed side approximately
ding over anterior half of upper jaw
nterior two-thirds of lower jaw. Mea-
nents of 6 specimens 42-75 mm.: caudal
16.0, depth 28.5-30.5, head 22.5-23.0,
al 28-31, postanal 73-78.

ther faintly cross-banded, the bands
se, irregular, incomplete, often widely
rupted, in form of 2 short bars placed
rsal and anal profile, on same vertical;
and at a moderate distance from caudal
often somewhat better developed than
s; irregularly shaded with dusky and
times washed with whitish; fins rather
colored; no distinctive markings; color
iption based on only a few of the speci-
examined, most specimens seemingly
l or turned dark by preservative.

udal rays. 14 and 1 specimens have fully
oped 10 and 11 rays, respectively; one
rays fused above their bases and 8 full
or a total of 10. One specimen with a
ic caudal is described below.

lotype. U.S.N.M. 131643; Albatross
on 2406; Lat. 28° 46′ N., Long. 84° 49′
ff St. George Island, Florida; 26 fath-
March 15, 1885; 42 mm.

ratypes. Two specimens obtained with
olotype (152734); off Cape San Blas,
da (131590-91, Albatross Station 2374,
thoms; 131593, Albatross Station 2372,
thoms); off Savannah (155233, Pelican
on 195-9, 24 fathoms) and St. Cathe-
Island (155230, Pelican Station 196-2,
thoms), Georgia; off Charleston, South
ina (155231, Pelican Station 182-22, 11
ms; and 155232, Pelican Station 194-11,
thoms); off Cape Lookout, North Caro-
(134272, Albatross Station 2609, 22
ms); off Halifax, Nova Scotia (92614,
ross Station 2505, 93 fathoms). Total
ypes 15, 26-78 mm., taken in 11-27
ms, except off Nova Scotia in 93
ms.

e specimens from Albatross Station
might be the same as were included in
riginal account of *piger* as noted below
that species.

e specimen, 37 mm. (153098), taken off
Beach, Florida, in 40 fathoms, has the
l with 12 rays distally, and one of these
represents a distal fusion of two rays
arise separately at the basal part of
n. According to the method of counting
adopted, it should be recorded as having
13 caudal rays. However, the caudal of this specimen is obviously teratic. Some of the rays are sinuous instead of being straight. What is more striking, their bases are not in a clear-cut regular row, as they normally should be, but they overlap one another and are generally highly irregular. At one point, what appear to be a few basal ossicles are irregularly aggregated in a group. It is evident that this specimen is abnormal with respect to the development of the caudal, and this count was omitted from Table 1. It has D 73, A 57 and Sc 60, agreeing with *minor* in these counts which are included in Tables 2-4.

Comparison. This species differs from all other species here treated in its low dorsal and anal counts. Its scale count also averages lowest, but this character intergrades widely with *parvus* and *pelicanus*, and *minor* is also nearest to those two species in the dorsal and anal counts. It is closely related to *parvus*, agreeing with it in normally having 10 caudal rays, while *pelicanus* normally has 12 caudal rays. Judged by the small samples examined, its size averages smaller than *parvus*.

Symphurus parvus, new species.

Aphoristia pigra Goode & Bean (in part), *Bull. Mus. Comp. Zool.*, 12: 154, 1886 (specimens from Albatross Station 2318 here forming in part basis of *S. parvus*).

Aphoristia diomediana Goode & Bean (in part), Ocean. Ichthy., p. 460, 1895 (specimen from Blake Station XXV examined).

Description. C 10 (11). D 78-84. A 64-68. Sc 60-73. Teeth on eyed side very small; in upper jaw extending for half its anterior length or some distance farther backward; in lower jaw extending for its greater part or nearly its entire length. Measurements of 5 specimens 53-78 mm.; caudal 13.0-15.5, depth 27.0-31.5, head 22.5-24.5. Preanal 27-30, postanal 74-77.

Two recently preserved specimens 44-48 mm., rather irregularly shaded or diffusely spotted all over without distinctive markings; other specimens examined apparently partly or wholly faded; the holotype, in addition to the faint shadings all over, with a faint suggestion of a cross band on posterior part of body and a better marked transversely oblong spot at a moderate distance in front of caudal base; another specimen with an irregularly rounded, large brown spot at dorsal profile, not far from caudal base; fins light colored, irregularly flecked and shaded with dusky.

Caudal rays. 8 specimens have 10 and 1 has 11 rays, all fully developed.

Holotype. U.S.N.M. 84491; Albatross Station 2318; Lat. 24° 25′ 45″ N., Long. 81° 46′ W.; off Boca Chica, Florida; 45 fathoms; January 15, 1885; 73 mm.

Paratypes. 4 specimens 53-78 mm., from the same Albatross Station as the holotype, as follows: 152733, one specimen originally very small teeth, and particular care must be exercised not to mistake them for teeth.

Species living in deep water generally have the dentition on the eyed side better developed.

Vertical distribution. Judged by the fair number of available depth records for the specimens examined, it is evident that the species of *Symphurus* are markedly selective in their vertical distribution. Some species have the same vertical distribution, or nearly so, but in many instances they differ in this respect. Some species differ widely in their vertical distribution, and depth records become of value in separating them. Even where two given species overlap in their vertical distribution, the extreme depth records are of value. Consequently, in collecting specimens of *Symphurus* it is of particular importance to record the depths at which they are taken.

Minor population differences. Some of the characters that are used for distinguishing the species, also differ intraspecifically with the minor population. Such minor differences in the number of dorsal and anal rays are shown to a limited extent in Tables 5-6 for three species and are also discussed under the accounts of those species.

KEY TO THE WESTERN ATLANTIC SPECIES OF *Symphurus*.

1a. Dorsal rays 72-83; anal rays 56-67; when dorsal and anal rays up to 84 and 68, respectively (in *parvus*), caudal without a definite spot. Scales 55-74. Teeth on eyed side of lower jaw extending over its greater part to nearly its entire length.

  2a. Caudal rays usually 10, sometimes 11. Caudal 12-16.

    3a. Dorsal rays 72-75. Anal rays 56-61. Scales 55-66 .... *minor* (p. 192).

    3b. Dorsal rays 78-84. Anal rays 64-68. Scales 60-73 .... *parvus* (p. 192).

  2b. Caudal rays 12. Dorsal rays 80-81. Anal rays 63-67. Scales 61-74. Caudal 17.5. *pelicanus* (p. 193).

1b. Dorsal rays 85-101; anal rays 69-85; when dorsal and anal rays down to 84 and 68, respectively (in *urospilus*), caudal with a well marked black spot. Scales 69-98.

  4a. Caudal with a large well marked spot. Caudal rays perhaps normally 11 (same count in 3 available specimens of both species). Teeth on eyed side of lower jaw absent or only a few present.

    5a. Dorsal rays 84-86. Anal rays 68-71. Scales 73-77. No definite spots on dorsal and anal . *urospilus* (p. 193).

    5b. Dorsal rays 93. Anal rays 75. Scales 88. Posterior part of dorsal and anal with definite spots *pterospilotus* (p. 194).

  4b. Caudal without a well marked spot. Caudal rays normally 10 or 12 depending on the species, variants having 11 rays comparatively few, in 2-6 per cent. of the specimens in the samples examined.

    6a. Caudal rays normally 10. Teeth on eyed side of lower jaw usually absent, sometimes a few present on side of jaw.

      7a. Scales 86-98. Dorsal and anal with definite spots posteriorly, well marked in light colored or faded specimens, obscure or imperceptible in dark colored fish. No black spot on head. Offshore. Dorsal rays 89-93. Anal rays 73-78 *diomedianus* (p. 194).

      7b. Scales 71-86. Dorsal and anal without well marked spots. Many specimens having a black spot on opercle. Inshore to moderately offshore. Dorsal rays 85-92. Anal rays 69-78.........*plagiusa* (p. 195).

    6b. Caudal rays normally 12.

      8a. Teeth on eyed side of lower jaw extending over its anterior half or its greater part. Deep water species, available depth records ranging 40-324 fathoms.

        9a. Dorsal rays 85-88. Anal rays 71-75.

          10a. Scales 69-73. Depth 29.0-30.5 in specimens 50-86 mm. in standard length *piger* (p. 197).

          10b. Scales 79-83. Depth 28.0-28.5 in specimens 53-59 mm. in standard length *pusillus* (p. 197).

        9b. Dorsal rays 96-98. Anal rays 82-83. Scales 92-95. Notably slender, depth 21.0-22.5 in specimens 90-115 mm. in standard length *marginatus* (p. 198).

      8b. Teeth on eyed side of lower jaw normally, or usually, absent, often a few teeth present on side of jaw in *plagusia*. Species living in shallow water or moderately offshore, greatest available depth record 18 fathoms.

        11a. Dorsal rays 87-92. Anal rays 70-77. Scales 69-80. Coast of the United States *civitatum* (p. 198).

        11b. Dorsal rays 90-98. Anal rays 76-82 (72 in one specimen out of 25). Scales 74-90. West Indies and Panama *plagusia plagusia* (p. 199).

        11c. Dorsal rays 95-101. Anal rays 78-85. Scales 80-92. Brazil *plagusia tessellata* (p. 200).

Frequency Distribution of the Number of Scales in Western Atlantic Species of *Symphurus*.

Species	Distribution																								
	55	58	61	64	67	70	73	76	79	82	85	88	91	94	97	100	103	106	109	112	115	118	121	124	127
minor	2	1	6	1	1																				
parvus			3	4		1	1																		
pelicanus			1		1		1																		
urospilus							1	1																	
pterospiloius												1													
diomedianus											1	4	4	6	1										
plagiusa						1	22	72	89	28	3														
piger						2	4																		
pusillus									1	2															
marginatus													1	1											
civitatum						3	11	16	7																
plagusia							1	5	2	8	6	1	1												
tessellata									1	8	12	8	2												
jenynsi																	4	4	4	2	2	1			
nebulosus																								1	2

TABLE 3.

Frequency Distribution of the Number of Anal Rays in Western Atlantic Species of *Symphurus*, Totals for the Species and Subspecies.

Species	Distribution																																				
	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85		92	93	94	95	96	97	98
minor	1	2	5	4	4	1																																
parvus									2	2	3	1	1																									
pelicanus								1			1	1																										
urospilus													1			1																						
pterospilotus																				1																		
diomedianus																		2	3	7	1	4	1															
plagiusa														3	16	27	50	40	22	12	1		1															
piger																	2	3																				
pusillus																1	1			1																		
marginatus																											2	1										
civitatum															1	2	1	8	12	10	3	1																
plagusia																	1				3	2	6	3	5	3	2											
tessellata																							1	1	2	11	10	5	3	1								
jenynsi																																1	1	7	5	3	3	
nebulosus																																		2				1

TABLE 2.

Frequency Distribution of the Number of Dorsal Rays in Western Atlantic Species of *Symphurus*, Totals for the Species and Subspecies.

Species	Distribution																																			
	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101		109	110	111	112	113	114
minor	5	3	6	3																																	
parvus							2		4		1	1	1																								
pelicanus									1	2																											
urospilus													1		1																						
pterospilotus																						1															
diomedianus																		1	3	6	3	4															
plagiusa														5	8	29	55	42	20	11	2																
piger														1	3		1																				
pusillus														1	1		1																				
marginatus																									1	1	2										
civitatum																3	2	5	14	10	3																
plagusia																			2	1	1	2	5	5	6	2	1										
tessellata																								1	5	9	8	7	2	2							
jenynsi																																4	7	1	4	3	1
nebulosus																																1	1			1	

TABLE 1.

Frequency Distribution of the Number of Caudal Rays in Western Atlantic Species of *Symphurus*.

Species	Distribution					
	9	10	11	12	13	14
minor		15	1			
parvus		8	1			
pelicanus				3		
urospilus			2			
pterospilotus			1			
diomedianus		17	1			
plagiusa	3	334	8			
piger				5		
pusillus				3		
marginatus				4		
civitatum			2	36		
plagusia			1	23	1	
tessellata			2	31	1	
jenynsi	2	19				
nebulosus						3

dorsal and anal fins, some practice is required in order to distinguish the caudal rays from the last ray of the other two fins. The caudal rays have their bases on a nearly straight transverse line, sometimes somewhat irregularly curved, and are closely approximated. The last dorsal or anal ray is more widely spaced from its adjacent caudal ray and its base is placed slightly more forward. After a little practice, the caudal rays may be distinguished by these slight peculiarities of structure, in nearly every fish, with very few somewhat doubtful individual specimens. The outermost caudal ray, both above and below, may be further distinguished in most specimens by another slight peculiarity of structure. Its base is somewhat broader than that of the other caudal rays and a little above its proximal end it has a slight burr-like outward projection. This is fairly evident, except in the small specimens, and it is somewhat better marked in some species than others.

Some of the caudal rays are occasionally irregular in structure, such irregularities being of three kinds, as follows: (1) A ray is sometimes incomplete, only a proximal portion of variable length being developed, sometimes as a short stump. (2) Only a small basal ossicle is present while the rest of the ray is undeveloped. In such instances the space between the two adjacent fully developed rays is usually somewhat greater than that between the other rays. It seems evident that in such variants a potential ray failed to develop. There is no sharp line of division between the preceding two categories, as these irregular rays occur in all degrees of imperfect development, from being represented by a mere, very small basal ossicle, to one in which only a moderate distal part remains undeveloped. (3) Two adjacent rays at a variable distance above their bases merge and become a single ray distally.

For the purpose of this statistical study and in Table 1, the partly developed ray, or the undeveloped ray represented by the basal ossicle only, were included in the count, and the two merged rays were counted separately. Such variants are not numerous and their numbers are stated under the accounts of the separate species. In *plagiusa* a total of 25 such variants was found in 345 specimens examined, or about 7 per cent. In this species the irregularity occurring most often falls in the above category (2) and the least often in category (3). In *diomedianus* 3 such variants out of 18 specimens examined fall partly or wholly in category (3). In *civitatum* 2 irregular variants were found among 38 specimens examined, and in *plagusia*, sensu stricto, 3 variants among 25 specimens. Four of the latter 5 variants belong to category (2) and one falls in category (1).

Except for the preceding moderate imperfections, the caudal fin is fairly regular. Of the many specimens examined, more than 600, the caudal count in only 3 fish could not be definitely determined. Two specimens were obviously injured in life and irregularly regenerated. The third is evidently an abnormal specimen and is described under its species, *minor*.

Scale count. The scale count here given refers to the number of oblique rows from the upper angle of the opercle to the caudal base. The scales run in fairly regular rows and when the scalation is complete a near accurate count is possible. However, in very many of the specimens examined the scales are missing on areas of variable extent. In such cases the count includes in part the rows of scale pockets which are sometimes indistinct. Consequently, the scale counts here given are only roughly approximate, but even so this character is of considerable value in separating the species. In Table 4 the counts of individual specimens are grouped by intervals of 3, the class headings representing their mid numbers.

Dentition. The dentition on the eyed side, especially that on the lower jaw, is of value in distinguishing some of the species. It is described under the accounts of the separate species and is also used in the key. This character is not easy to apply in practice. The teeth are small, partly hidden by the gums and lips, and may be discerned properly only with a strong magnifier and after the preserving fluid has been thoroughly evaporated. Also, the mucous membrane lining the jaws is usually covered with papillae which in superficial appearance simulate uniform and moderate width; band in lower jaw shorter and wider, shaped somewhat like the segment of a circle or moderately crescentic with the straight or slightly curved margin entad and the well curved margin ectad; dentition on eyed side very moderately or poorly developed, the teeth small, few or moderate in number, eyed side of upper jaw with a narrow band of teeth at symphysis in 2-3 irregular rows, tapering backward to one row, or one row throughout, or a small group of a few teeth near symphysis; eyed side of lower jaw with one row, or with very few teeth, or altogether toothless, depending on the species and intraspecific individual variability. Opercle separated by a posterior emargination into two lobes, the upper lobe smaller. Branchiostegal membranes united, their point of union at base of ventral fin. Isthmus free. Pseudobranchiae very moderate. No slit behind fourth gill arch. Gill rakers nearly obsolete, indicated as slight, uneven, variable protuberances on gill arch (not examined in all species). Body and head with ctenoid scales, those on anterior part of head becoming more or less embedded; caudal scaled at its base, the scales continued backward in rows between the rays for some distance, scaleless distally; dorsal and anal with short rows of small scales along the proximal part of the rays. Lateral line absent. Dorsal origin over eye; dorsal and anal continuous with caudal. Pelvic fin unpaired, placed at isthmus, normally having 4 rays (the rays counted in 364 specimens representing all species, only 3 variants, one each in *diomedianus, plagiusa* and *jenynsi,* having 3 rays). Pectoral absent. All rays segmented and unbranched.

Most characters in the preceding description of the genus are nearly common to the several species examined, and are not repeated under the species descriptions. Also, the western Atlantic species of *Symphurus* are unusually uniform in their structure, and not many characters are available for the purpose of distinguishing the separate species. For these two reasons, the species descriptions given below are very brief.

The number of rays in the caudal, dorsal and anal fins and that of the scales are of primary importance in the identification of the species. While the intraspecific variability of these counts or the spread of their frequency distributions is moderate in comparison with other flatfishes, it is yet rather extensive, and the best way of applying these characters in practice is by reference to tables showing their frequency distributions. As far as the available material permitted, such data have been determined and are presented in Tables 1-6.

The dentition on the eyed side is of some specific value as discussed below.

Color marks are of value in distinguishing some of the species. A black spot on the opercle of *plagiusa,* and spots on the dorsal and anal fins of *diomedianus,* are of limited value, as a majority but not all specimens, in both species, have these marks developed. A well marked spot on the caudal is present in the specimens examined of *urospilus* and *pterospilotus,* the latter also having spots on the dorsal and anal. Wide cross bands on the body often constitute a prominent feature of specimens of *Symphurus.* However, in three species, *plagiusa, civitatum* and *plagusia,* of which fair or good samples were examined, including many recently preserved specimens, this color pattern depends on individual variation, although the relative frequency of occurrence of banded individuals appears to differ also with the species. Within the range of every one of the three species, the bands are well marked, or absent altogether, or present in various incomplete stages of development.

Proportional measurements, on the whole, are also rather uniform and are of only limited value in separating the species. Five measurements have been determined on a rather small number of specimens and are given under the accounts of the species as follows, named in order of their taxonomic importance: depth, caudal, head, preanal and postanal. Two species, *marginatus* and *nebulosus,* are markedly slender. The depth might also prove to be of value in distinguishing *pelicanus, piger* and *pusillus* from one another and from their close relatives, on examination of adequate samples of those three species. The caudal is notably short in *jenynsi* and *tessellata* and rather long in *pelicanus.* The other measurements do not differ much with the species, although a determination of adequate samples will likely show average differences, that is, divergent frequency distributions of various degrees of intergradation.

Two terms here used in stating proportional measurements, not commonly used in descriptive ichthyology, have the following meaning: preanal and postanal, the distance from the anal origin to the point of contact of a vertical tangent with the anterior curvature of the head, and the caudal base, respectively. The head was measured on the eyed side between the above point of contact and that of the upper lobe of the opercle. All proportional measurements are expressed as a percentage of the standard length. Under the accounts of some species where figures for proportional measurements are segregated by two size groups, those for the smaller specimens are given in parenthesis.

Three of the characters here used to distinguish the species, the numbers of caudal rays and scales, and the dentition on the eyed side, need to be discussed briefly.

Caudal fin ray count. The number of rays in the caudal fin differs with, and is of much importance in the classification of, the species of *Symphurus.* Every species of which good and fair samples were examined has a normal or decidedly predominating count. For instance, the normal count in *plagiusa* is 10, while in *plagusia* and *civitatum* it is 12. As the caudal is continuous with the

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14.

Western Atlantic Tonguefishes with Descriptions of Six New Species.

Isaac Ginsburg.
U. S. Fish and Wildlife Service.

(Plates I-III).

The main object of the investigation here recorded, was to determine the species of *Symphurus* inhabiting the east coast of the United States, particularly the Gulf coast, and to elaborate the specific characters by which they are distinguishable. However, in order to properly understand, define and distinguish those species, it was found necessary to study all the species from the western Atlantic, including the West Indies.

The specimens forming the basis of this account are those in the U. S. National Museum, the Museum of Comparative Zoology and the Bingham Oceanographic Collection. Also, a valuable collection made by the U. S. Fish and Wildlife Service research boat *Pelican* which obtained specimens of four of the new species here described, including a good sample of *civitatum* from the coast of Louisiana.

All the available specimens of the western Atlantic only were studied in detail. For comparative purposes, I also examined in detail, in the National Museum, one specimen each of the following species from the American Pacific coast, namely, *fasciolaris, atramentatus, leei, sechurae, paitensis, atricauda* and *elongatus,* type specimens of the five species named first. All these specimens represent species which are different from those in the western Atlantic. As the intraspecific variability of the Pacific species was not determined, their relationship to one another and to the Atlantic species is not discussed in this paper.

One species, *Symphurus trewavasae* Chabanaud (*Bull. Mus. Paris,* (2)20:508, 1948), from Brazil, is not included, as none of the specimens examined, judged by their characters and locality of capture, coincide with Chabanaud's account. According to the figures given in the original account, *trewavasae* about agrees with *plagiusa* in the number of caudal rays and scales and proportional measurements. In comparing his species with *plagusia* and *plagiusa,* Chabanaud calls special attention to its supposedly large eye. However, in 5 specimens of *plagiusa* measured, the eye varies from 11 to 15 per cent. of the head. This range includes that of *trewavasae* given in its account. The numbers of dorsal and anal rays of *trewavasae* average a little higher than in *plagiusa,* but the two species widely overlap in these counts. The specimens on which *trewavasae* is based were collected in deeper water than that in which *plagiusa* lives on the coast of the United States. These two species should be directly compared in greater detail.

The other western Atlantic species described by Chabanaud in the same paper, *S. sumptuosus,* is apparently based on a specimen of *diomedianus,* and that name is placed below in its synonymy.

Symphurus Rafinesque.

Symphurus Rafinesque, Indice D'Ittiologia Siciliana, p. 52, 1810 (genotype *Symphurus nigrescens* Rafinesque by subsequent designation)—Jordan & Goss, Rep. U. S. Comm. Fish. 1886:321, 1889 (*Symphurus nigrescens* Rafinesque designated as genotype).

Sinistral, strongly compressed; symmetrically shaped; greatest depth in anterior half of length, the depth nearly uniform for a considerable distance, thence tapering both ways; the anterior taper moderate; posterior taper beginning at about end of anterior two-thirds of standard length, varying a little both ways, except in *jenynsi* at about the middle, the depth decreasing rapidly to caudal base. Eyes small, slightly smaller than short snout; the two eyes separated by a very narrow interorbital space in small specimens, touching each other or very nearly so in the larger specimens; anterior margin of upper eye slightly in advance of that of lower, infrequently both about aligned on same vertical. Snout short and very blunt, the anterior profile forming a nearly continuous broad curve. Mouth very small, its posterior angle under anterior margin of lower pupil, varying slightly both ways, except slightly more backward in *civitatum* and *plagusia;* asymmetrical, moderately curved on eyed side, notably curved on blind side. Anterior nostril on eyed side a well developed tubule, placed at some distance in front of lower eye, the tubule short on blind side; posterior nostril with a raised edge, placed directly in front of and between the eyes. Dentition chiefly developed on blind side, the teeth rather small, subequal or the outer teeth moderately larger, in bands; band in upper jaw of nearly in same jar with holotype; 74330, originally labelled cotypes of *Aphoristia pigra*. Off Sombrero Light, Florida (153090, 50-60 fathoms, 63 mm.). Off Palm Beach, Florida (153088, 20-30 fathoms, 44 mm.; 153097, 40 fathoms, 48 mm.). Total paratypes 7, 44-78 mm., taken in approximately 20-60 fathoms.

The following two specimens evidently also belong to this species: Off Palm Beach, Florida (153087, 58 mm.). This specimen is injured and its fin ray counts are not accurately determinable. Blake Station XXV (47657, 66 mm., probably West Indies). The latter is apparently the specimen referred to by Goode & Bean in their 1895 account of *A. diomediana*. Its dorsal, anal and scale counts, included in Tables 2-4, fall at the extreme end on the right of the distribution of *parvus*.

Comparison. This species is structurally nearest *minor* and the differences between them are discussed under that species. It is also compared with *pelicanus* under the account of the latter.

Symphurus pelicanus, new species.

Aphoristia diomediana Goode & Bean (in part), Ocean. Ichth., p. 460, 1895 (specimen listed below from Albatross Station 2121-2122 evidently included in account cited).

Description. C 12. D 80-81. A 63-67. Sc 61-74. Teeth on eyed side very small, in lower jaw extending for nearly its entire length, in upper jaw ending at some distance before angle of mouth. Measurements of 3 specimens 60-71 mm.: caudal (in two specimens) 17.5, depth 27.5-28.5, head 22.0-23.5, preanal 26-30, postanal 75-78.

Body and fins light yellowish, irregularly and very lightly shaded, almost immaculate. Blind side of Trinidad specimen thickly sprinkled with very small dark points, these points more sparsely distributed and finer in the two Texas specimens; all three specimens with a large dark area directly behind head at ventral profile on both sides of fish, evidently the black peritoneum showing externally.

Caudal rays. Two specimens have 12 complete rays; 1 has 2 rays fused above their bases and 10 complete rays or a total of 12.

Holotype. U.S.N.M. 155234; Pelican Station 115-5; Lat. 26° 43′ N., Long. 96° 51′ W.; off Padre Island, Texas; 25 fathoms; February 4, 1939; 60 mm.

Paratypes. U.S.N.M. 155235; Pelican Station 116-4; Lat. 26° 34′ N., Long. 96° 32′ W.; off Padre Island, Texas; 45 fathoms; February 5, 1939; 70 mm. U.S.N.M. 74331; Albatross Stations 2121-2; Station 2121, Lat. 10° 37′ 40″ N., Long. 61° 42′ 40″ W., off Trinidad, B. W. I., 31 fathoms; Station 2122 is a short distance away and in 34 fathoms; one specimen 60.9 mm. in standard length, about 71 mm. in total length.

Comparison. This species nearly agrees with *parvus* in the number of dorsal and anal rays and scales. It differs in having 12 caudal rays. The two species also differ on the average in the caudal length and body depth, *pelicanus* having a longer caudal and slenderer body. There may be some minor color differences, but the small samples examined do not permit the evaluation of such probable differences. This species should also be compared with *piger*, the two agreeing in the number of caudal rays and the dentition on the eyed side. They differ in the number of dorsal and anal rays as shown in Tables 2-3. When adequate samples of *pelicanus* and *piger* become available, their frequency distributions in the number of those rays will likely be found to approach closely. This species differs from *piger* also in having a slenderer body and longer caudal.

This species is named after the U. S. Fish and Wildlife Service research boat *Pelican*, which brought together a very valuable collection of specimens from the southeast coast.

Symphurus urospilus, new species.

Description. C 11. D 84-86. A 68-71. Sc 73-77. Eyed side of large specimen with a very few teeth at symphysis of upper jaw, none on lower; in small specimen teeth in upper jaw more numerous and 2 teeth on side of lower jaw. Measurements of 2 specimens 146 and 42 mm.: caudal 11.5 (13.5), depth 34 (32), head 19 (23.5), preanal 24 (30), postanal 82 (76).

A large black spot on caudal, nearer distal margin than base of fin, surrounded by a hyaline area; brownish with transverse, broad, brown bands deeper than ground color, 3 crowded bands on head, 9 on body, the last 3 faint and more approximated than others (scales largely missing on posterior part of body and bands very faint). The above color description is from the large, fairly recently preserved specimen. The small specimen, long in preservative, has the cross bands faint, but the caudal spot is sharply marked and ocellated with white.

Caudal rays. Both specimens have 11 complete rays.

Holotype. U.S.N.M. 155225; Pelican Station 181-8; Lat. 32° 01′ N., Long. 80° 11′ 30″ W.; off Savannah, Georgia; 12 fathoms; February 3, 1940; 136 mm.

Paratype. U.S.N.M. 73262; Fish Hawk Station 7154; Lat. 29° 32′ N., Long. 83° 58′ 30″ W.; off Pepperfish Key, Florida; 10.5 fathoms; November 7, 1901; 42 mm.

Comparison. Considering that in all species except *pterospilotus*, 11 caudal rays occur only in variants, in most species in rather infrequent variants, it is highly probable that the 11 caudal rays in both available specimens will prove to be the normal number in this species. It differs from all other species, again excepting *pterospilotus*, in having a caudal spot. It is compared with *pteropilotus* under the account of that species. The number of dorsal and anal rays and scales in this species is rather low, being at the borderline between the first two groups of species separated in the key.

Symphurus pterospilotus, new species.

Description. C 11. D 93. A 75. Sc 88. Eyed side of upper jaw with a few teeth near symphysis; that of lower jaw with very short, slender papillae, without teeth. Measurements of a specimen 127 mm.: caudal 11.5, depth 30, head 19, preanal 27, postanal 81.

Dusky shaded with darker, faint traces of diffuse, irregular and incomplete cross bands; caudal and posterior part of dorsal and anal dark; dorsal with 4 somewhat unevenly spaced black spots; the first near beginning of its posterior third, the last near its junction with caudal; 4 similar spots on anal opposite to those of dorsal; an elongate black spot nearly centered on caudal.

Caudal rays. 11 complete rays in the single specimen examined.

Holotype. U.S.N.M. 87770; Isla de Flores, Uruguay; W. L. Schmitt.

Comparison. This species has the unique combination of 11 caudal rays, a spot on the caudal, and spots on the dorsal and anal fins. It agrees with *urospilus* in the number of caudal rays and its spot, but differs in the number of dorsal and anal rays and scales. Unlike *urospilus* it has spots on the dorsal and anal and it is not as deep bodied. It agrees with *diomedianus* in having spots on the dorsal and anal, but differs in having a well defined spot also on the caudal, and it is very highly probable that it differs further from *diomedianus* in the number of caudal rays.

Symphurus diomedianus (Goode & Bean).

Aphoristia diomediana Goode & Bean, *Proc. U. S. Nat. Mus.*, 8:589, 1886 (off Tortugas, Florida; 26 fathoms)—Goode & Bean (in part), Ocean. Ichthy., p. 460, pl. 90, fig. 378, 1895 (off Tortugas, Yucatan, Trinidad and Dominica; the specimen from Trinidad here referred to *pelicanus*, that from Dominica not examined).

Symphurus diomedianus Jordan & Evermann, *Bull. U. S. Nat. Mus.*, 47 (3): 2711, 1898 (after Goode & Bean).

Symphurus sumptuosus Chabanaud, *Bull. Museum Paris*, (2) 20:509, 1948 (Rio de Janeiro).

Description. C 10 (11). D 89-93. A 73-78. Sc 86-98. Teeth on eyed side absent or a few present at symphysis of upper jaw and on middle of lower jaw. Measurements of 7 specimens 133-207 mm.: caudal 10.0-12.5, depth 28.5-31.0, head 18-20, preanal 23-26, postanal 78-83.

Almost uniformly brownish, or with faint traces of cross bands, or irregularly mottled or blotched with dark shades; posterior part of dorsal and anal variably dusky, sometimes nearly black, with 1-4 rounded irregularly spaced spots on each fin, not far from caudal, on about posterior fifth of standard length, these spots moderately or sharply marked, sometimes faint or hardly perceptible, especially in specimens with very dark fins.

Caudal rays. Three specimens out of 18 have the structure of the caudal irregular, in all three 2 of the rays being fused at a

TABLE 5.

Frequency Distribution of the Number of Dorsal Rays in Three Western Atlantic Species of *Symphurus*, Segregated by Minor Populations.

Species and Populations	Distribution													
	85	86	87	88	89	90	91	92	93	94	95	96	97	98
diomedianus														
United States and Yucatan					1	3	3	1	2					
Brazil							3	2	2					
plagiusa														
Long Island Sound to Cape Canaveral	3	2	18	29	18	13	8	1						
Key West to Tampa	2	4	8	10	7	1								
Apalachicola to Corpus Christi		1	2	15	17	6	3							
Cuba			1					1						
plagusia														
Cuba									1	2			1	1
Hispaniola							1			2	1	1		
Puerto Rico						2		1		1		1		
Panama									1		4	2	1	

variable distance above their bases to form a single ray distally, as follows. One variant has 1 ray incomplete, 2 rays fused and 7 complete rays or a total count of 10. Another variant has 2 rays fused and 8 complete rays. The third variant has 2 rays fused and 9 complete rays or a total count of 11. The other 15 specimens have 10 complete rays.

Specimens examined. From off the following localities: North Carolina (152029); Key West (107322, 129945) and Tortugas (37347, the type), Florida; Isle Derniere (154978, collected by the Pelican) and Atchafalaya Bay (154977, 154979; Pelican), Louisiana; Cabo Catoche, Yucatan (133935); Rio de Janeiro (M. C. Z. 889 and 4665) and Victoria (M. C. Z. 11377), Brazil. Total examined 18 specimens 68-207 mm. The largest specimen is from the coast of North Carolina.

Comparison. This species normally has 10 caudal rays like *plagiusa*, and differs from that species in the higher scale count. The numbers of dorsal and anal rays average considerably higher. The black spots on the dorsal and anal, when present, distinguish this species from *plagiusa* and all other species examined from the western Atlantic, except *pterospilotus;* but the spots are hardly perceptible in some specimens. The vertical distribution also separates it incompletely from *plagiusa*. Seven available depth records for *diomedianus* range from 17 to 50 fathoms, and one specimen was taken at 8 fathoms; while *plagiusa* is most common inshore and ranges only to 14 fathoms offshore. It is compared with *pterospilotus* under the account of that species.

Synonymy. According to Chabanaud's description, the type specimen of his *sumptuosus* agrees with *diomedianus* in the number of caudal, dorsal and anal rays and scales, in the presence of spots on the dorsal and anal and the absence of a spot on the caudal. That *diomedianus* does occur on the coast of Brazil is proved by the 7 specimens examined in the Museum of Comparative Zoology from that coast as listed above. It is, therefore, concluded that *sumptuosus* is a synonym of *diomedianus*.

Populations. The composite sample examined from Brazil averages a little higher dorsal and anal counts than that from the coasts of the United States and Yucatan, as shown in Tables 5-6.

Symphurus plagiusa (Linnaeus).

Pleuronectes plagiusa Linnaeus, Syst. Nat., ed. 12, p. 455, 1766 (no locality, received from Dr. Garden and probably came from Charleston)—Goode & Bean, *Proc. U. S. Nat. Mus.*, 8:196, 1886 (description of type, see below).

Plagusia fasciata De Kay, *Zool.*, New York, pt. 4, Fishes, p. 304, 1842 (South Carolina, based on an unpublished illustration by Holbrook).

Symphurus plagiusa Jordan & Goss, Rep. U. S. Comm. Fish. 1886:325, 1889 (Beaufort, Charleston, Pensacola and Key West) —Jordan & Evermann, *Bull. U. S. Nat. Mus.*,

TABLE 6.

Frequency Distribution of the Number of Anal Rays in Three Western Atlantic Species of *Symphurus*, Segregated by Minor Populations.

Species and Population	Distribution													
	69	70	71	72	73	74	75	76	77	78	79	80	81	82
diomedianus														
United States and Yucatan					1	3	6		1					
Brazil					1		1	1	3	1				
plagiusa														
Long Island Sound to Cape Canaveral	2	6	13	30	22	13	6							
Key West to Tampa	1	6	7	11	4	2	1							
Apalachicola to Corpus Christi		3	5	9	14	7	5	1						
Cuba			1							1				
plagusia														
Cuba									1	1		1	1	1
Hispaniola				1					1	1	1	1		
Puerto Rico								3		1		1		
Panama										3	2	1	2	

47 (3): 2710, 1898 (same localities as preceding).

Description. C (9) 10 (11). D 85-92. A 69-76 (78). Sc 71-86. Eyed side with teeth on anterior half of upper jaw or for a shorter distance; usually no teeth on eyed side of lower jaw, sometimes a very few teeth at its side. Measurements of 5 specimens 124-147 mm. and 6 specimens 54-77 mm.: caudal 11.0-11.5 (11.5-13.0), depth 29.5-31.5 (27-31), head 18.5-20.5 (21.0-22.5), preanal 24-26 (24-30), postanal 79-83 (77-81).

Color very variable; cross bands darker than ground color, present or absent, when present in various stages of development from almost solidly continuous to interrupted, incomplete or irregular in various degrees, or only faintly indicated; sometimes with few or many intensely dark, very small specks; a large black spot on opercle, centered on its upper lobe, present in the majority of the larger specimens, especially those recently preserved, usually faint or absent in the smaller specimens and often also in the larger; sometimes a smaller solid or interrupted black spot also on lower posterior part of head; dorsal, anal and caudal fins faintly or moderately dusky, usually with a darker pigment along the rays.

Caudal rays. Of 345 specimens of which the caudal was examined as recorded in Table 1, 25 specimens or 7.2 per cent. have an irregular or imperfect structure, as follows:

The 3 variants with 9 caudal rays have them fully developed, without irregularities in structure.

Among the 334 specimens recorded as having 10 rays, 22 have an imperfect structure, as follows: 9 have one of the 10 rays in the form of a very small basal ossicle; 2 have 2 such ossicles representing 2 rays; 1 has 3 ossicles and only 7 fully developed rays; 7 have 1 ray in various degrees of incompleteness, in some of them in the form of a very short stump; 2 have 2 of the rays fused at some distance above their bases; 1 specimen has 2 rays in the form of stumps, 2 rays fused above their base and 6 complete rays.

Among the 8 variants recorded in Table 1 as having 11 rays, 5 specimens have them fully developed, while 3 have 1 ray in the form of a basal fragment and 10 complete rays. These 8 variants are important from the practical standpoint of identification in distinguishing *plagiusa* from *civitatum.* Seven of these 8 variants are identified as being specimens of *plagiusa* on the following grounds: 5 have a black spot on the opercle which is a unique color mark of *plagiusa;* 2 which lack a definite opercular spot, were taken in shallow water situations where only *plagiusa* lives, one by seining the beach on Cat Island, Mississippi, the other by trawling in Barataria Bay, Louisiana. The eighth specimen, small and faded, was taken off Anclote Key, Florida, in 6¼ fathoms (133980). As it differs from normal specimens of *plagiusa* in having, in addition to 10 fully developed caudal rays, only an extra very small basal ossicle, the probabilities are that it is a variant of *plagiusa,* but this is not altogether certain. By an outside chance, it might possibly be a variant of *civitatum.*

Specimens examined. Long Island Sound (59056, 5 specimens 41-55 mm.). Chesapeake Bay (Cape Charles City, Cape Charles, Thimble Shoal, Ocean View; altogether 13 specimens 52-176 mm.). Many lots ranging from Cape Hatteras, North Carolina, to Key West, Florida, on the Atlantic coast and from Cape Sable, Florida, to Laguna Madre, Texas, on the Gulf coast. Also, 2 specimens from Cuba (37750, 107365). The largest specimens are 189 mm. (one from St. Augustine, Florida, B.O.C. 3708; another from "Florida Keys," M.C.Z. 11060).

This is the most common species of *Symphurus* on the Atlantic and Gulf coasts of the United States. Altogether 130 constituent samples comprising 347 specimens were examined. It is an inshore species and ranges offshore to a depth of 14 fathoms. Depth records are available for 32 of the lots. They were mostly taken in open water offshore in 2-14 fathoms. Many of the other lots, perhaps all of them, were taken by shore seining or by trawling in the inner shallow water bays and estuaries. The latter situations evidently constitute the center of abundance of *plagiusa* with respect to the vertical distribution of the species of *Symphurus,* and of all those examined no specimens of any other species were taken in such locations.

Comparison. This species is usually distinguishable by the combination of normally having 10 caudal rays, the presence of a black spot on the posterior part of the head in many specimens, its dorsal, anal and scale counts and its usual shallow water habitat. In the number of caudal rays it agrees with *diomedianus* and is further compared with it and with *civitatum* under the accounts of those species.

Nomenclature. Goode & Bean (cited above) present some measurements of Linnaeus' type specimen of *plagiusa* which, converted to percentages of the standard length, give depth 23 and head 17. These measurements do not apply to the common American species here treated, and this species seemingly should be designated *fasciata* De Kay. However, I hesitate to alter well established usage without confirmation of the measurements and further study of the questions involved. Therefore, current usage is here continued.

Populations. This species is comparatively homogeneous in its structure, with the possible exception of the Cuban population. Tables 5-6 in which the dorsal and anal counts are segregated into three major geographic regions, show only slight differences. The population of the northern part of the Gulf averages the highest count, that from Key West to Tampa, inclusive, the lowest, and the population on the Atlantic coast is intermediate, but the differences are slight.

The 2 Cuban specimens examined have 10 caudal rays and 73-77 scales, agreeing with *plagiusa* in these counts. One of them (107365) has D 87, A 71, which counts fall within the range of variation of *plagiusa*, somewhat to the left of a median. The other specimen (37750) has D 92, A 78. The dorsal count of this specimen falls in the last column, on the right of the distribution of the species as a whole, while the anal count falls altogether out of the range of the species. Either the latter specimen is an unusually extreme variant, or the Cuban population of *plagiusa* is markedly variable. Another possibility is that the Cuban population averages higher dorsal and anal counts than the populations on the coast of the United States.

Symphurus piger (Goode & Bean).

Aphoristia pigra Goode & Bean (in part), *Bull. Mus. Comp. Zool.*, 12:154, 1888 (specimens of more than one species included in original account, see below)—Goode & Bean (in part), Ocean. Ichthy., p. 460, pl. 110, fig. 377, 1895 (same specimens listed as in preceding citation).

Symphurus piger Jordan & Goss, Rep. U. S. Comm. Fish., 1886:326, 1889 (after Goode & Bean)—Jordan & Evermann, *Bull. U. S. Nat. Mus.*, 47 (3): 2705, 1898 (after Goode & Bean).

Symphurus pusillus Hildebrand (not Goode & Bean), *Carnegie Inst. Washington Publ.* 535:50, 1941 (Tortugas, Florida).

Description. C 12. D 85-88. A 72-73. Sc 69-74. Teeth on eyed side extending approximately over anterior three-quarters of both jaws. Measurements of 2 specimens 116-133 mm. and 3 specimens 57-98 mm.: caudal 14(12.5-15.0), depth 33-34 (29.0-30.5), head 22.5-23.0 (23.0-24.5), preanal 28-30 (in all 5), postanal 75-77 (73-74).

Color of the three large Tortugas specimens pale with sharply contrasting, somewhat irregular, rather narrow cross bands. The other three specimens probably more or less faded; the one specimen from off Sombrero Light with one cross band and a small part of another; the lectotype brownish, irregularly shaded with faint traces of darker cross bands. Fins light colored or moderately dusky, moderately marked with darker dots and small elongate or irregular spots.

Caudal rays. The five specimens in which the caudal rays were counted have 12 complete rays.

Specimens examined. Off St. Kitts, W. I. (M.C.Z. 27965, 250 fathoms, the lectotype, 98 mm.). Tortugas (117287, 140-197 fathoms, 2 specimens 115-133 mm., the smaller specimen badly damaged; 117176, no depth record, about 116 mm.), off Sombrero Light (153099, 50-60 fathoms, 62 mm., a teratic specimen having only one eye) and off Palm Beach (153089, 40 fathoms, 57 mm.), Florida.

Comparison. The number of dorsal rays and scales of *piger* falls near the lower end of the distribution of *plagiusa* and *civitatum*, while the anal count falls at or near the middle of their ranges. It differs from those two species in having the dentition on the eyed side better developed, and it differs further from *plagiusa* in having 12 caudal rays. In its structural characters it is nearest *pusillus*. Judged by the specimens examined, *piger* differs from *pusillus* in having fewer scales, a deeper body, longer head and shorter postanal. More extensive samples are needed to elaborate adequately the differences between *piger* and *pusillus*.

Lectotype. Specimens of at least two species were included for certain in the original account of *Aphoristia pigra*, and probably more than two. Specimens are listed from Blake Station XXIII, and Albatross Stations 2318, 2374, 2425 and 2405. As the phraseology used in the original description for type designation is not in consonance with present day taxonomic practice, and a question might be raised as to which species the name *piger* is to be applied, the specimen from Blake Station XXIII, M. C. Z. 27965, is hereby designated as the lectotype. The specimens from Albatross Station 2318, U. S. N. M. 74330, now labeled as cotypes of *A. pigra*, are included above in the account of *parvus*. Also, specimens from Albatross Station 2374 are included above under the account of *minor*, but it is not altogether certain whether they are the same specimens referred to by Goode & Bean. Specimens from the other two stations listed in the original description could not be located now.

Symphurus pusillus (Goode & Bean).

Aphoristia pusilla Goode & Bean, *Proc. U. S. Nat. Mus.*, 8:590, 1885 (off Long Island)—Goode & Bean, Ocean. Ichthy., p. 461, pl. 110, fig. 379, 1895 (based on preceding specimens).

Symphurus pusillus Jordan & Evermann, *Bull. U. S. Nat. Mus.*, 47(3): 2710, 1898 (after Goode & Bean).

Description. C 12. D 85-88. A 71-75. Sc 79-83. Teeth on eyed side rather well developed in both jaws, continuously extending over their anterior half or farther backward. Measurements of 3 specimens 53-59 mm. in standard length, the caudal damaged: depth 28.0-28.5, head 20.5-22, preanal 27-28, postanal 77-81.

The three small specimens examined apparently faded, rather light brownish, with traces of cross bands in two specimens, fins yellowish.

Caudal rays. All 3 specimens have 12 complete caudal rays.

Specimens examined. Off Long Island, New York (28730, Fish Hawk Station 921, Lat. 40° 07′ 48″ N., Long. 70° 43′ 54″ W., 67 fathoms; 28778, F. H. Station 941, Lat. 40° 01′ N., Long. 69° 56′ W., 79 fathoms); the three cotypes, their measurements given above.

Comparison. This species is nearest *piger* as discussed under the account of that species.

Symphurus marginatus (Goode & Bean).

Aphoristia marginata Goode & Bean (in part), *Bull. Mus. Comp. Zool.*, 12:154, 1886 (specimens from Blake Station CLXXXI and Albatross Station 2376 included in account below; specimen from Fish Hawk Station 1154 included below in account of *nebulosus;* specimens from off St. Vincent not examined)—Goode & Bean (in part), Ocean. Ichthy., p. 459, pl. 110, fig. 376, 1895 (preceding specimens listed).

Symphurus marginatus Jordan & Goss, Rep. U. S. Comm. Fish. 1886:323, 1889 (after Goode & Bean)—Jordan & Evermann, *Bull. U. S. Nat. Mus.*, 47(3): 2706, pl. 387, fig. 949, 1900 (after Goode & Bean).

Symphurus diomedianus Hildebrand (not Goode & Bean), *Carnegie Inst. Washington Publ.* 535:49, 1941 (Tortugas, Florida).

Description. C 12. D 96-98. A 82-83. Sc 92-95. Teeth on eyed side extending over greater part of both jaws. Measurements of 2 specimens 102-127 mm.: caudal 11-13, depth 21.0-22.5, head 17-19, preanal 24-25, postanal 78-80.

Specimens examined probably faded, brownish, traces of rather small, diffuse dusky spots, giving impression of rough arrangement along longitudinal lines; a dark, very fine streak at dorsal and anal base; fins at posterior end of fish dark.

Caudal rays. All 12 rays in the four caudals counted, fully developed.

Specimens examined. Off Mississippi Delta (M. C. Z. 27967, Lat. 28° 42′ N., Long. 88° 40′ W., 321 fathoms, Blake). Off Dauphin Island, Alabama (131634, Lat. 29° 03′ 15″ N., Long. 88° 16′ W., 324 fathoms, Albatross). Besides the above 2 type specimens, their measurements given above, 3 specimens examined from Tortugas, Florida (117174, taken in "197 plus fathoms;" 117288, no depth data); in very bad condition, but body rather slender, fin ray counts about agree with the 2 type specimens, and apparently of the same species. The determinable fin ray counts of the Tortugas specimens included in Tables 1-3 and the account of the species.

Comparison. This is a deep water species. It has the dentition on the eyed side fairly developed as in *piger* and *pusillus* with which it also agrees in having 12 caudal rays. It differs rather widely from those two species in the dorsal, anal and scale counts. The body is slenderer than in any species here treated, except *nebulosus*.

Symphurus civitatum, new species.

Description. C (11) 12. D 87-92. A 70-77. Sc 69-80. Teeth on eyed side of upper jaw extending over anterior half of jaw or less, none on lower jaw. Angle of mouth approximately under posterior margin of lower pupil or middle of eye. Measurements of 10 Gulf specimens 91-147 mm. and 2 Atlantic specimens 121-153 mm., the latter in parenthesis: caudal 10.5-13.5 (10.5-11.5), depth 30-34 (31-32), head 19.5-21.0 (18.0-18.5), preanal 24-26 (22-24), postanal 78-82 (81-82).

Cross bands usually absent or faint, sometimes rather fairly marked; opercle without a black spot, occasionally with a dusky area; caudal and posterior part of dorsal and anal variably dusky, sometimes nearly black.

Caudal rays. Of 36 specimens with 12 caudal rays, 2 have one of the rays represented by a basal ossicle only, the other 34 having 12 complete rays. Two specimens have only 11 complete rays. The latter were taken in 8 and 10 fathoms in company with other specimens of *civitatum* having the normal number of 12 rays. The probabilities favor the conclusion that they are specimens of *civitatum,* but there is some shade of doubt. By long odds they might possibly be examples of *plagiusa.*

Holotype. U.S.N.M. 155227; Pelican Station 77-4; Lat. 29° 06′ 30″ N., Long. 89° 40′ W.; off Mississippi Delta; 9½ fathoms; July 8, 1938; 125 mm.

Paratypes. Other 36 Gulf specimens 91-147 mm., in 19 constituent samples taken off the following localities: Aransas Pass and Galveston, Texas; Calcasieu Pass, Marsh Island, Atchafalaya Bay, Isle Derniere, Grand Isle and Grande Terre, Louisiana; Mobile, Alabama; St. Joseph Bay, Florida. Depth records are available for 16 of these constituent samples and range 4-12 fathoms. Also, 2 specimens 121-153 mm. from the Atlantic, taken at Cape Hatteras, North Carolina, and Cape Canaveral, Florida, in 14 and 10 fathoms, respectively.

Six of the 22 constituent samples examined were separated from a mixture of *civitatum* and *plagiusa.* Of the above specimens the *Pelican* took 23 in 11 constituent samples in the Gulf, all on the coast of Louisiana, and one specimen off Cape Canaveral. Based on the samples examined, this is evidently a moderately offshore species which is fairly common on the northern Gulf coast and not so common on the Atlantic coast.

Comparison. This species is very close to *plagusia.* These two represent allopatric, composite, somewhat intergrading populations, as discussed further under the account of *plagusia,* and it would not be altogether out of place to treat them as two coordinate subspecies. However, the degree of divergence between the two composite populations is high, being at least at the borderline between species and subspecies. The index of divergence, according to the composite samples examined, is 8 when the number of dorsal rays is used as the basis for comparison and 7 when the number of anal rays is used. This degree of divergence seems nearer that of species. At any rate, *civitatum* is here treated as a full species until it and *plagusia,* especially the latter, are more adequately sampled.

For the practical purpose of identification, *civitatum* needs to be compared with *plagiusa;* as it occurs through the greater part of the geographic range of that species, the two are sometimes taken together, and the dorsal, anal and scale counts are nearly the same in both. The chief character that distinguishes them is the number of caudal rays, normally 10 in *plagiusa* and 12 in *civitatum*, but this difference is not absolute, as out of 383 specimens examined of both species 10 have 11 rays. Most specimens of these two species are further distinguished by their habitat and by color. *S. civitatum* does not live in shallow water and is not taken in the inner bays or by shore seining in open water. Also, most of the larger, well preserved specimens of *plagiusa* have a black spot on the head, while *civitatum* lacks such a spot. Often these two differences are not applicable. Many specimens of *plagiusa* lack the black spot. Also, while *plagiusa* is the only species of *Symphurus* on the east coast of the United States that inhabits shallow water, it also extends offshore over the range of *civitatum*, and of 82 lots of both species examined, that comprise 2 or more specimens, 6 contained a mixture of both, apparently taken together in the same trawl. Nevertheless, by these two differences, 7 out of the 10 specimens which have 11 caudal rays are confidently referable to *plagiusa* as discussed under that species. That leaves only 3 specimens out of 383, or less than one per cent., about which there is a shade of doubt regarding their proper placement by species. The grounds for placing these 3 specimens by species, one in *plagiusa* and two in *civitatum*, are stated above.

A minor difference between the two species is that in *civitatum* the posterior angle of the mouth is usually slightly more backward with relation to the position of the eye, than in *plagiusa*. This criterion furnishes some slight additional evidence that the 10 variants with 11 caudal rays have been properly placed, 8 and 2 in *plagiusa* and *civitatum*, respectively. However, this character is not decisive, and often specimens cannot be referred to their proper species when it alone is used as a criterion.

Populations. The two Atlantic specimens examined have a shorter head than 10 specimens measured from the Gulf, as indicated above.

Symphurus plagusia

(Bloch & Schneider), sensu lato.

Aphoristia ornata Gunther, Cat. Fish. Brit. Mus., 4:490, 1862 (Atlantic coasts of tropical America).

Symphurus plagusia Jordon & Goss, Rep. U. S. Comm. Fish. 1886:324, 1889 (Havana; Brazil)—Jordan & Evermann, *Bull. U. S. Nat. Mus.*, 47(3): 2709, 1898 (Havana; Brazil).

Description. C (11) 12 (13). D 90-101. A (72) 76-85. Sc 74-92. Teeth on eyed side of lower jaw absent, or a few present in individual variants. Angle of mouth under middle of lower eye or posterior margin of its pupil. Cross bands present or absent; caudal and posterior part of dorsal and anal black or dusky; no definite, well marked spots on caudal, dorsal, anal and opercle.

Distinctive characters and relationship. This species is characterized by the combination of normally having 12 caudal rays, its dorsal, anal and scale counts, the poorly developed dentition on the eyed side and the lack of definite spots on the caudal, dorsal and anal. As here treated, it is divisible into two subspecies, *plagusia* in the West Indies and Central America, and *tessellata* on the coast of Brazil and Uruguay. The index of divergence between the two in the frequency distribution of the dorsal and anal rays (Tables 2-3), amounts to 15, which is of subspecies magnitude.

From one viewpoint *plagusia* might be regarded as a species that extends from the coast of the United States to South America; that is, including *civitatum;* and is composed of a number of diverging populations the degrees of divergence of which differ widely. From this viewpoint the populations of *plagusia*, sensu lato, might be divided into three major groups which might be treated as subspecies, *civitatum* on the coast of the United States, *plagusia*, sensu stricto, in the West Indies and Central America, and *tesselata* on the coast of Brazil and Uruguay. However, the divergence of the population on the coast of the United States is rather abrupt. *S. civitatum* diverges to a greater extent from the subspecies *plagusia* than *tessellata* does from the latter. The degree of divergence of *civitatum* is about that of species magnitude and it is here treated as a full species, as discussed under its account.

Symphurus plagusia plagusia

(Bloch & Schneider).

Plagusia subcinerea, cauda attenuata . . . Browne, The civil and natural history of Jamaica, p. 445, 1789 (Jamaica; nonbinomial).

Pleuronectes plagusia Bloch & Schneider, Syst. Ichthy., p. 162, 1801 (based on Browne).

Aphoristia fasciata Goode & Bean (not De Kay), Ocean. Ichthy., p. 458, pl. 110, fig. 374, 1895 (Jamaica).

Description. C (11) 12 (13). D 90-98. A (72) 76-82. Sc 74-90. Dentition on eyed side rather weak; teeth in upper jaw extending over its anterior two-fifths or less; usually no teeth on eyed side of lower jaw, often a few teeth present on side, near its middle or on its anterior third. Measurements of 12 specimens 85-195 mm. and 6 specimens 49-76 mm.: caudal 9-12 (9.5-12.0), depth 27.0-30.5 (25-28), head 19-21 (20.5-22.0), preanal 23-27 (26-28), postanal 77-83 (76-81).

Cross bands usually present, variable, often interrupted or irregular, sometimes faint or imperceptible; caudal and posterior part of dorsal and anal usually black, often moderately dusky; posterior part of head often with a large dusky area, but no well defined black spot; no distinctive color marks.

Caudal rays. Of the 23 specimens recorded in Table 1 as having 12 rays, one of the rays is incomplete in 3, being in the form of a small basal ossicle in 2 specimens, and as a short stump in one. All 3 imperfect specimens are from Panama. One specimen has 11 and another 13 caudal rays, all complete.

Specimens examined. Taken at or off the following localities: Cuba (35108; M. C. Z. 11200, 11269 and 25982); Jamaica (37348); Haiti (133671); Dominican Republic (108369, 108372); Puerto Rico (50178, M. C. Z. 28843); Porto Bello (81652), Fox Bay (81653-5) and Fort Randolph (144792), Panama; Trinidad (123112). Total examined, 25 specimens, 44-195 mm. Only 2 depth records are available, 17-18 fathoms, for the two specimens taken off the Dominican Republic by the *Caroline.* Some of the others at least apparently were taken by shore seining.

Comparison. The relationship of the subspecies is discussed above under the account of its species.

Populations. This subspecies has a comparatively wide geographic range, and judged by the small samples examined it appears to be markedly heterogeneous. The dorsal and anal counts are segregated by local populations in Tables 5-6. The Cuba and Panama populations average higher counts than those from Hispaniola and Puerto Rico.

Symphurus plagusia tessellata (Quoy & Gaimard).

Plagusia tessellata Quoy & Gaimard, Voy. Uranie, Zool., p. 240, 1824 (Rio de Janeiro).

Plagusia brasiliensis Agassiz, in Spix, Selecta Genera et Species Piscium . . . Brasiliam, p. 89, pl. 50, 1829 (Brazil).

Description. C (11) 12 (13). D 95-101. A 78-85. Sc 80-92. Teeth on eyed side of upper jaw extending approximately over its anterior third; no teeth on eyed side of lower jaw. Measurements of 10 specimens 124-221 mm.: caudal 8.5-9.5, depth 26.0-29.5, head 18.0-19.5, preanal 24-26, postanal 77-84.

Most specimens examined apparently faded, a few specimens perhaps showing about normal color in preservative, or not so faded, having a nearly uniform brownish color, without definite cross bands, and caudal and posterior part of dorsal and anal black or dusky; no distinctive markings.

Caudal rays. Of the 31 specimens entered in Table 1 as having 12 caudal rays, 2 have one of these rays incomplete, represented by a small basal ossicle. One specimen has 2 rays fused at some distance above their bases and 11 complete rays, or a total count of 13. Two specimens have only 11 rays, all of them complete.

Specimens examined. Rio de Janeiro, Santos, Pernambuco and Rio Sao Francisco, Brazil; Uruguay. Total examined, 34 specimens, 76-221 mm., all except one from Brazil.

Comparison. The relationship of this subspecies is discussed under the account of its species.

Nomenclature. The name *ornatus* Lacépède (Hist. Nat. Poiss., 4:659 and 664, 1802), is sometimes used by authors to designate this subspecies, or that name is placed in the synonymy of *plagusia,* sensu lato. Lacépède's *ornatus* was based on a specimen the locality of which was unknown. It is described as having a lateral line and 8 or 9 deeply dark bands. It is much more likely that this specimen came from the Indo-Pacific region than from the western Atlantic.

Symphurus jenynsi Evermann & Kendall.

Symphurus jenynsi Evermann & Kendall, *Proc. U. S. Nat. Mus.*, 31:108, fig. 4, 1907 ("probably from the market at Buenos Aires").

Symphurus bergi Thompson, *ibid.* 50:414, pl. 2, fig. 2, 1916 (Montevideo).

Description. C 9-10. D 109-114. A 92-97. Sc 102-118. Beginning to taper posteriorly at about middle of standard length, varying a little both ways (some evidence to show shape changing with growth, beginning to taper more posteriorly in the largest specimen). Teeth on eyed side of upper jaw in a small group at a short distance behind symphysis; no teeth on eyed side of lower jaw. Measurements of 3 specimens 233-346 mm., 9 specimens 165-195 mm. and 5 specimens 128-159 mm., the following proportional measurements given in three groups in same order, beginning with largest: caudal 6.5-8.0, 7.0-8.5, 8-9; depth 27.5-32.5, 26-30, 26.5-29.0; head 15.5-16.5, 16-18, 17.5-19.0; preanal 21-24, 21-24, 23-28, postanal 83-87, 80-86, 78-83.

Nearly uniformly colored or irregularly shaded or spotted, the shadings sometimes aggregated to form rather diffuse cross bands; fins moderately dusky; no distinctive markings.

Caudal rays. In the 21 specimens counted, all the caudal rays are fully developed, including the two variants having 9 such rays.

Specimens examined. Buenos Aires, Argentina (55573, type of *jenynsi,* 181 mm.). Other 21 specimens 117-346 mm., in 10 constituent samples, including the type of *bergi* (76852), all taken on the coast of Uruguay, at or off Montevideo and Isla de Flores, definite depth records not available, probably taken both inshore and offshore. This is evidently a common species on the coast of South America.

Comparison. This species is readily distinguished from the others here treated by its high dorsal, anal and scale counts in combination with the presence of 9-10 caudal rays.

Symphurus nebulosus (Goode & Bean).

Aphoristia nebulosa Goode & Bean, *Bull. Mus. Comp. Zool.*, 10:192, 1883 (off Charles-on, South Carolina)—Goode & Bean, Ocean. chthy., p. 458, pl. 110, fig. 375, 1895 (based n type specimen).

Aphoristia marginata Goode & Bean (in art), *Bull. Mus. Comp. Zool.*, 12:154, 1886 specimen from Fish Hawk Station 1154 elongs to *nebulosus*).

Description. C 14. D 109-113. A 94-98. Sc 23-128. Teeth on eyed side extending over nterior half or greater part of both jaws. 3ody notably elongate. Upper lobe of head otably small, lower lobe large and notably rojecting beyond lower. Measurements of specimens 45.5-77.5 mm. in standard ength, the caudals damaged: depth 21.5-3.5, head to apex of upper lobe 19.0-20.5, o apex of lower lobe 21.0-23.5, preanal 27-30, ostanal 73-75.

Almost uniformly colored, reddish or yelowish brown, the three available specimens erhaps faded, side of abdomen black, apparntly the black peritoneum showing on the utside; no distinctive markings.

Caudal rays. The 3 specimens examined have 14 complete rays.

Specimens examined. Fish Hawk Station 1154; Lat. 39° 55′ 31″ N., Long. 70° 39′ W.; off Long Island, New York; 193 fathoms (152842). Blake Station 316; Lat. 32° 7′ N., Long. 78° 37′ 30″ W.; off Charleston, South Carolina; 229 fathoms (M. C. Z. 27966, the holotype). Albatross Station 2664; Lat. 29° 41′ N., Long. 79° 55′ W.; off Matanzas Inlet, Florida; 373 fathoms (84490). Measurements of these 3 specimens given above.

Comparison. This species differs from all others here treated in having 14 caudal rays. The scales are more numerous than in all other species, approaching *jenynsi* in this character. In the number of dorsal and anal rays it about agrees with *jenynsi* and differs from all other species. In its notably slender body, it about agrees with *marginatus* and differs from the others. Altogether, it is a very distinctive, readily recognizable species.

EXPLANATION OF THE PLATES.

PLATE I.

ig. A. *Symphurus minor;* from the holotype; U. S. N. M. 131643; off St. George Island, Florida; 42 mm.

ig. B. *Symphurus parvus;* from the holotype; U. S. N. M. 84491; off Boca Chica, Florida; 73 mm.

ig. C. *Symphurus pelicanus;* from a paratype; U. S. N. M. 155235; off Padre Island, Texas; 70 mm.

PLATE II.

ig. D. *Symphurus urospilus;* from the holotype; U. S. N. M. 155225; off Savannah, Georgia; 136 mm.

ig. E. *Symphurus pterospilotus;* from the holotype; U. S. N. M. 87770; Isla de Flores, Uruguay; 127 mm.

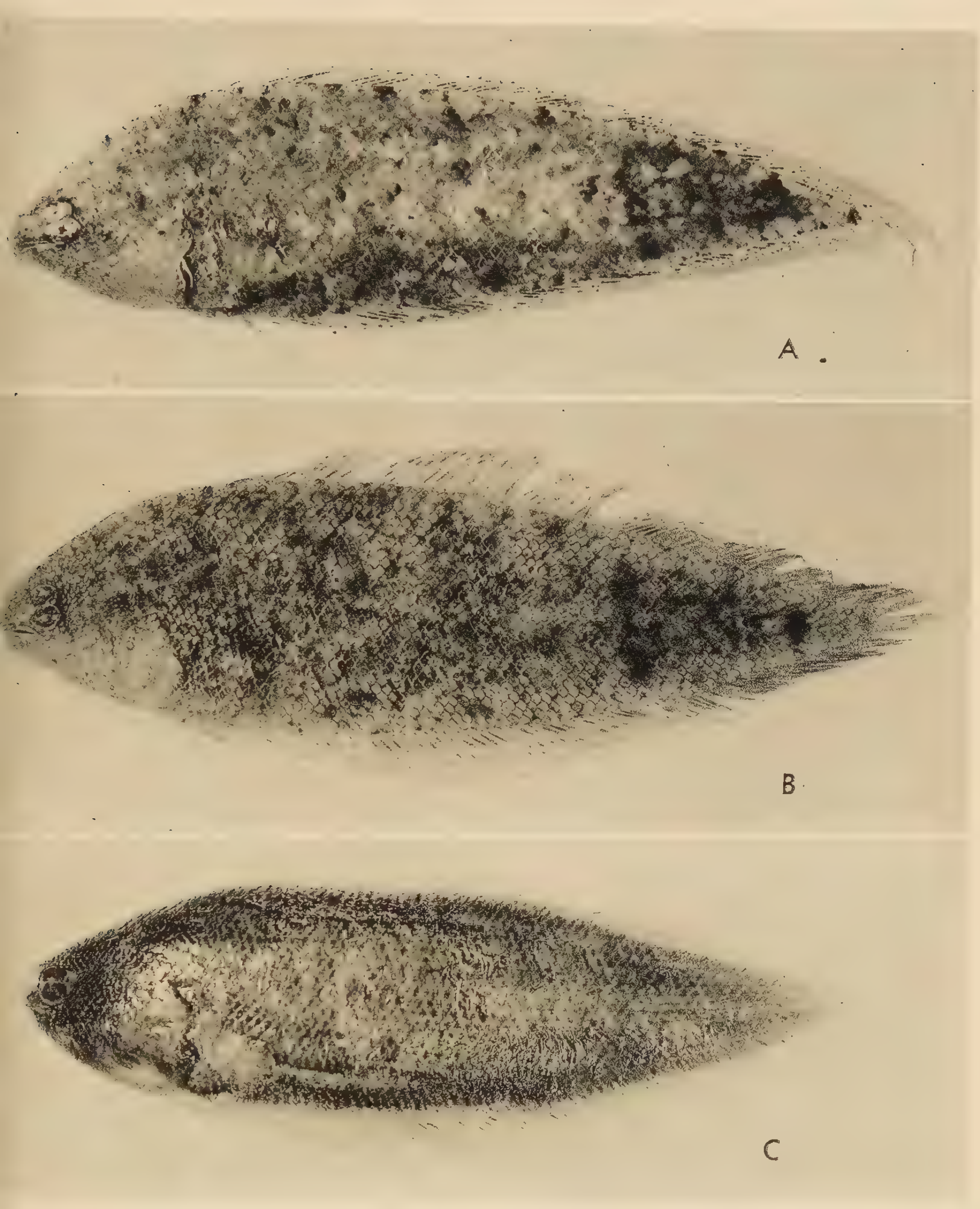
Fig. F. *Symphurus diomedianus;* from the holotype; U. S. N. M. 37347; off Tortugas, Florida; 152 mm.

PLATE III.

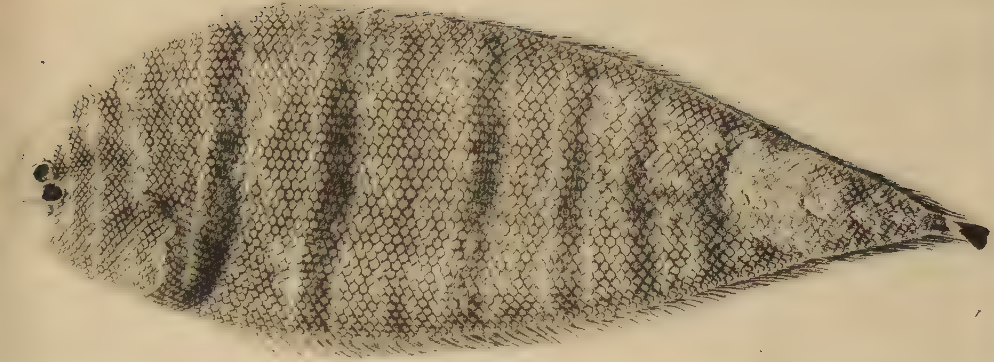
Fig. G. *Symphurus plagiusa;* U. S. N. M. 154962; off Cumberland Island, Georgia; 123 mm.; many specimens lack black opercular spot.

Fig. H. *Symphurus civitatum;* from the holotype; U. S. N. M. 155227; off Mississippi Delta; 125 mm.

Fig. I. *Symphurus civitatum;* a well marked banded variant; U. S. N. M. 120081; Galveston, Texas; 125 mm.



WESTERN ATLANTIC TONGUEFISHES WITH DESCRIPTIONS OF SIX NEW SPECIES.



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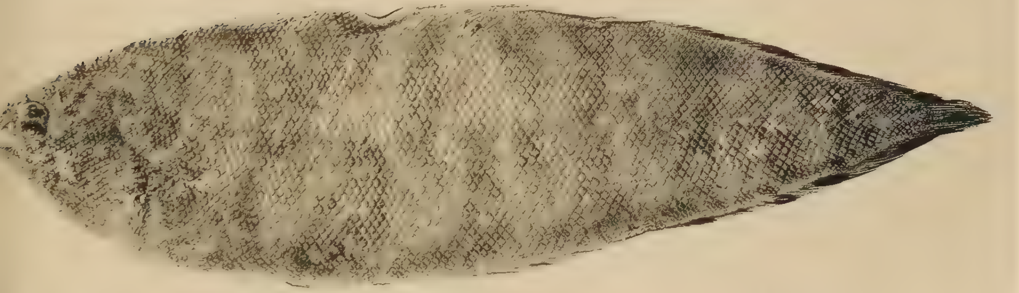

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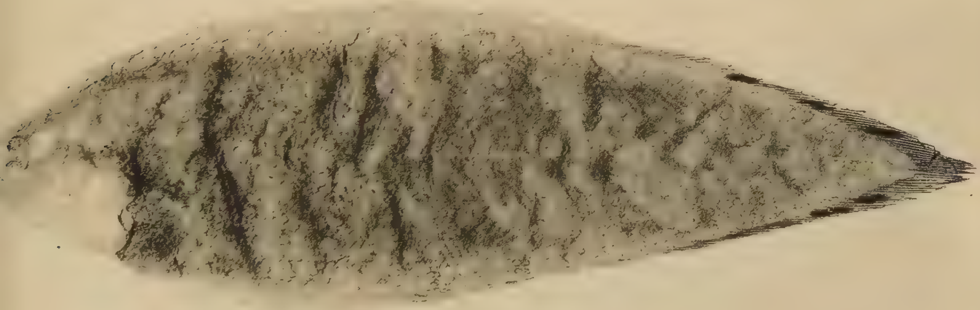

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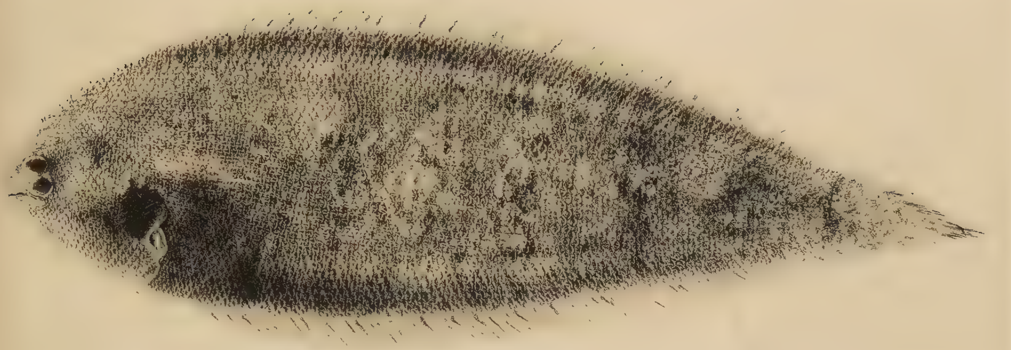

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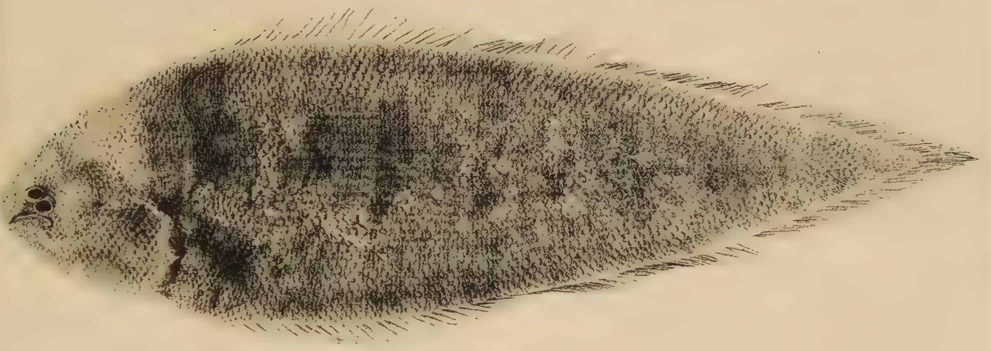

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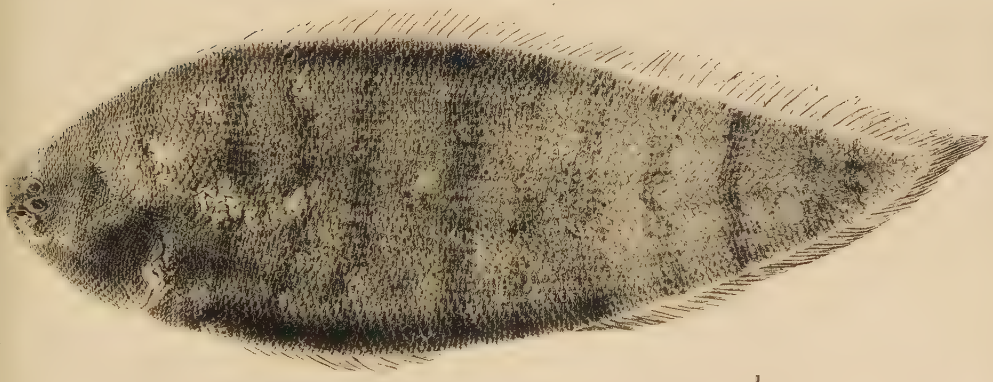

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WESTERN ATLANTIC TONGUEFISHES WITH DESCRIPTIONS OF SIX NEW SPECIES.

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THE EFFECT OF MAN ON SHELLFISH POPULATIONS

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Introduction

Shellfish populations more than any other marine species are readily accessible since they occur in shallow waters and are often exposed at low tide. Man's effect on these populations is therefore easily demonstrated.

Oysters, clams, and mussels have been subject to fisheries throughout history, contributing greatly to the food supplies of early peoples. Greene's ''History of Boothbay'' (1906) states: ''In winter when the interior was closed down under ice and snow he [the Indians] came to the seashore, where he had all that that locality produced for sustenance, clams, oysters, fish and birds; and in these regions, before civilization had placed its mark upon the territory, all the game worked seaward, too, in the winter, on account of the great depth of snow back from the ocean.''

Effect of Man

Early accounts always speak in terms of ''bountiful supply'' of shellfish along our shores and it is probably true that the small fisheries of the natives did not deplete the supply. Later when the white man settled along the coast and began utilizing shellfish for food, we begin to hear of scarcity of oysters and clams where formerly they had been abundant. Kellogg (1898) described the depletion of the soft clam as follows: ''The falling off in the supply of clams in Rhode Island has for some time been regarded with serious concern, and it is still rapidly diminishing. Clam diggers everywhere on Narragansett Bay whom I have met during the present summer (1898) have given the most discouraging reports. In some localities, where clams were abundant four or five years ago, almost none can now be attained.''

Belding (1909) described depletion in Massachusetts as follows: ''The decline of the clam supply is a matter of general knowledge. People who live along the seashore realize that they can no longer gather the amount of clams they once could dig with ease from the same flats. On the southern shore of the State especially, it is oftentime difficult to obtain even enough for family use.''

Later reports concerning the soft clam, *Mya arenaria,* which will serve as an example of shellfish for this discussion, tell of even more serious shortages. By 1948, the soft clam had become so scarce in Massachusetts that less than 10 per cent as many diggers were employed as formerly. Even in Maine, the western counties were becoming depleted and the industry was shifting to the eastward. Washington County, the most easterly, now produces 64 per cent of Maine's clams.

What caused this great depletion of clams? Several reasons can be given which are ''effects of man'':

1. Fishing

The low intensity of the fishery before the white man came to America and even during the early colonial days was insufficient to cause depletion. Expanding human populations increased the demand for clams as food. The real market for clams began, however, during the 1930's when Howard Johnson restaurants popularized the fried clam. Fishing intensity has steadily increased to meet this demand. Resulting high prices have added to the incentive to produce more clams but even so the demand exceeds the supply.

2. Sewage pollution

Soft clams occur naturally in bays or estuaries which become polluted as the population increases. Today, over 60 per cent (Turner. 1948) of Massachusetts clam flats are closed because of sewage pollution. Even in Maine, which has a relatively low population, 57 areas, including about 20 per cent of the clam flats, are closed to digging because of sewage pollution.

Closing of these vast areas has concentrated the digging on the remaining flats, thereby hastening depletion.

An example of the economic importance of flats closed by pollution is Jones Creek, Scarborough, Maine. This 32-acre beach had been closed because of pollution for several years but was opened April 13, 1950, after a survey by the Maine Department of Sea and Shore Fisheries. At the present time over 3,200 bushels of clams have been removed by commercial diggers for an average of 100 bushels per acre. The value of these clams is estimated at $21,000, or over $650 per acre. A crop of this size could be expected every 3 years, so the annual return per acre would be over $200, which compares favorably with the best farm crops.

3. Industrial pollution

River mouths where soft clams live become settling beds for sludge and silt produced by industry. Chemicals dumped into the rivers flow over the clams. Under conditions like these it is small wonder that the soft clam is disappearing from such places.

4. Other human activities

Clam flats, unappealing to many and unrecognized for their true value, are sacrificed to make way for ''progress.'' One fine clam flat in Massachusetts became a huge airport. Others became sites of new factories. Channels were dredged through some, and silt heaped on others. Each of these changes reduces the area suitable for production of clams.

EFFECT OF OTHER FACTORS THAN MAN

Man, however, is not the only cause of changes in shellfish abundance. Records show three previous periods of scarcity or even ''disappearance'' of clams along the New England Coast. About the beginning of the century, Kellogg (1899) described the serious condition of the flats and the sudden disappearance of the soft clam.

Records of the Clam Commissioner of the Town of Ipswich, Massachusetts, show the period of 1916-1918 was one of clam scarcity severe as that today. Again in the early 1930's shortages of clams were reported in a number of places. In between these periods of scarcity occurred times when the clams and the clam diggers thrived. So far no explanation has been advanced which can place the whole responsibility for these periods of scarcity and abundance on man. Depletion from commercial digging can only reach a certain level below which it becomes unprofitable. It is unlikely that commercial digging could cause the complete ''disappearance'' of the clams recorded in many places.

Extremely high mortality rates of clams were observed during the summer of 1949 by biologists of the Fish and Wildlife Service Clam

Investigations at Plum Island, Massachusetts. In some places 60-90 per cent of the clams had recently died. Similar mortalities were reported that summer from New Jersey, Connecticut, and Maine. Our pathological studies suggest infestations of minute parasites, or even bacteria may have caused the death of these clams. Mead (1901) reported a similar mortality in his transplanting experiments in Rhode Island as follows: ". . . The clams planted at low tide fared like those in experiment 5, i.e., they were nearly all dead when examined in the summer, the empty shells, however, showing they had lived about two months and that the mortality was sudden, although the cause is not known."

The effect of such mass mortalities may be greater than previously realized and may be a primary cause of the periodic disappearance of clams. There are some indications that these mortalities are associated with periods of unusually warm weather.

Natural predators may wipe out a clam population. A planting of seed clams in our experimental farm in Massachusetts was completely destroyed in 3 weeks by the horseshoe crab, *Limulus polyphemus*. Three species of the clam borer *Polynices* occur along the Atlantic Coast and where abundant, these enemies can quickly consume a new set of clams.

The green crab, *Carcinides maenas* (L.), is a serious predator on the soft clam. Although seldom seen at low tide, and therefore usually not recognized as a predator, this crab is capable of digging the clams from their holes, cracking their shells, and devouring them.

Gulls and ducks feed upon clams when they are available, but are not considered as serious as other predators.

The physical environment of a clam flat is subject to great changes. Floods, droughts, freezing, heat, ocean currents, as well as poisonous plankton and lack of food, can affect the poor clam who is unable to move from his burrow. Perhaps among these factors will be found other causes for his periods of abundance and scarcity.

FUTURE OF THE FISHERY

Fisheries generally pass through some of the following stages:

1. Low intensity fishery
2. High intensity fishery
3. Depletion
4. Research
5. Regulation of the fishery
6. Restocking
7. Control of enemies

Shellfisheries also have passed through these stages. Let us take the example of the eastern oyster which reached its peak production in the 1890's and has since fallen off to a low level. Research discovered the spawning and setting habits of the oyster and pointed the way for restocking through collection of seed oysters on old oyster shells. Further research disclosed the enemies of the oysters and set forth some methods for their control. States began to regulate the fishery by controlling fishing methods, allowing a certain catch limit, or a certain open season for fishing on public bars. All of these measures, however, failed to restore the oyster fishery to its former level since the demand was greater than could be supplied by natural production. It was not until public reefs became private farms that the oyster industry reached its fullest development.

We have then the eighth stage in the development of a fishery:

Private farming.—This stage applies only to shellfish among marine fisheries at the present time, but there it presents a method of bringing production to the maximum. Oyster culture under private management has become one of our greatest food industries through the cooperation of industry and biological research.

The clam industry also can have this eighth stage of development when the colonial custom of free fishing rights on all beaches is overthrown. Most New England coastal towns now have it within their power to grant leases of tidelands to individuals, although this is rarely done. When this practice becomes general, clam farming can begin to develop.

We recognize, however, that much research must precede the development of private clam farming. Methods must be found for securing seed clams in large numbers and at a low cost. Predators must be controlled and the cause of the extensive mortalities which occurred in 1949 must be discovered. All of these questions, plus many more, are being studied by the Fish and Wildlife Service Clam Investigations and substantial progress is being made. We regard private farming as a potentially practical solution to the present shortage of clams.

Each of the stages listed above is an effect of man, but the last five are the most important. Research, regulation of the fishery, restocking, control of enemies, and private farming are efforts designed toward restoring the resource. It is significant then, that man has it in his power to restore shellfish populations, as well as to destroy them.

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DISCUSSION

MR. WILLIAM JACKSON (Maryland): You speak of predator control. I am wondering if there is not some way in which the influence of the predators can be reduced through environmental improvement rather than by direct control.

MR. GLUD: That may be possible with clam flats. We recognize that certain types of beaches, certain types of environment are more favorable to certain species such as the horseshoe crab, whereas other flats are not infested as yet by the horseshoe crab. It may be that an area free of predators would limit their effect. In addition to that we have tried fencing in some of the plantings, and in that way have been successful in keeping some of the larger predators out of the area without eliminating them for control of populations. We would rather prevent their entrance into the area in which we are interested.

CHAIRMAN WALLACE: I would like to ask whether the clam studies have progressed to a point where private farming of clams is a practical enterprise from strictly a commercial standpoint?

MR. GLUD: No, we have had rather discouraging luck in some of our plantings from predation and a number of other factors, but we do regard it as a potentially practical solution to the problem. We are still working on it, but we still believe that there will be ways of counteracting the effect of predators, disease, and so forth.

CHAIRMAN WALLACE: Are the state regulations which are now in effect in most of the coastal states of any real value in maintaining beds or increasing the productivity of those beds at the present time in your opinion?

MR. GLUD: Will you repeat the question again please?

CHAIRMAN WALLACE: My question was, are the regulations which are now in effect of any important value in maintaining the populations in the light of your findings? Has there been some progress in production and other things?

MR. GLUD: There are practically no regulations for the soft clam except for the 2-inch minimum size. There is no open or closed season in any area except for the one which they are now considering in the present legislature in Maine. However, at the present time there are no open or closed seasons, and there is practically no regulation except size.

CHAIRMAN WALLACE: Well, is the size limit an effective method of regulation?

MR. GLUD: It is effective as an economic measure, but we are not certain that it is effective as a biological measure.

DISCUSSION LEADER UNDERHILL: Mr. Glud, what have you found to be the effect of the commercial horseshoe crab operations? I am thinking particularly of the king crab pounds in Delaware Bay. Do you feel they remove enough of the predators to have any effect on clam populations?

MR. GLUD: Those in Delaware and in New Jersey probably do not have since the soft clam is relatively scarce. Most of the fisheries having hard clams are not affected as much by the horseshoe crab, and most of the commercial fishermen don't fish for the soft clam. They don't fish for the horseshoe north of Cape Cod where the soft clams are produced.

DISCUSSION LEADER UNDERHILL: There is one other general comment I would like to make on this paper because I think the whole philosophy of management in this country is expressed by it: That is the apparent feeling of Mr. Glud and the other clam investigators that public management of this resource is not going to be successful, that the whole concept of the resource belonging to the people is going to break down. If we are going to continue the operation and development of this resource, we are going to have to approach it by the European, the Continental system, of private ownership and private management. I wonder if anyone has a comment on the thinking which ties this whole field together.

MR. GLUD: I don't think anybody would advocate all tidelands being given over into private hands. In the first place, not all of them are equally suitable for private farming of shellfish. I think that all of us recognize that we have to have certain areas for recreation, such as on Cape Cod, where a great many people come for vacations and expect to go out and dig some clams. In cases like that we would certainly advocate public beaches and probably stocking by the towns or the states to keep up the recreational value of the area. There are a lot of other places, however, where the commercial use is much more important than the recreational value to the public, and it is in places like that where we would recommend private farming.

DR. THOMAS H. LANGLOIS (Ohio): I am interested in your suggestion of the possibility of clam farming as a commercial venture, and I am thinking of it from this standpoint. The government has found that the best forest management practices can be carried out by large scale operations rather than by small individual operations. I believe that oyster farming is now praticed in some parts of Long Island Sound. Are you thinking of clam farming in terms of small scale enterprise or simply as one large business which might be operated more efficiently? What is your idea?

MR. GLUD: I believe that we would advocate the small holdings. The clam diggers are rather a different sort of a group [laughter], and their clam digging is usually a part-time enterprise. They are usually a marginal income group which turn to digging clams when there are not more profitable occupations. Most of them along the New England Coast are used to very low incomes and it would not take very many acres of clam flats.

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Cocarboxylase and Adenosine Triphosphate as Growth Factors for *Hemophilus piscium*[1]

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INTRODUCTION

An investigation of a proposed new species of the bacterial genus *Hemophilus* (*H. piscium*) revealed that a thermolabile factor was necessary (1); this requirement was not satisfied by coenzyme I, which is a growth factor for certain other members of this genus. The present note presents evidence that diphosphothiamine (cocarboxylase) and adenosine triphosphate (ATP), in low concentrations, are highly active in replacing natural materials.

EXPERIMENTAL

Several strains of *H. piscium* were grown on blood agar for 48 hr., emulsified and washed three times in 0.9% saline, and then diluted to give 90% transmission of the incident light (Klett-Summerson photoelectric colorimeter). As the inoculum, 0.05 ml. of this suspension was used. This method of preparing the inoculum was found to give less erratic results than the more conventional methods of harvesting microorganisms grown in a liquid medium. The results were read in the colorimeter at the end of 48 hr. incubation at 22°C.

All tests were carried out in a basal medium of the following percentage composition: Difco-proteose peptone No. 3, 2.0; glucose, 1.0; NaCl, 0.5; "Tween 40,"[2] 0.005; distilled water, pH 7.3 with NaOH; 10 ml./tube.

RESULTS AND DISCUSSION

The results are compiled in Table I, an inspection of which shows the inability of the basal medium to support growth, the growth response to diphosphothiamine, ATP, and "fish peptone."[3] The effect of phosphatase cleavage on diphosphothiamine and the natural material is also included.

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[1] Part of a dissertation to be presented in candidacy for the degree of Doctor of Philosophy.

[2] A gift of the Atlas Powder Company, Wilmington, Delaware.

Preliminary assays indicated that a growth response could be detected in the presence of from 0.1 to 0.5 μg. of diphosphothiamine and from 5 to 10 μg. of ATP/ml. of medium; the degree of response varied depending upon the strain used. An increase in the concentration of diphosphothiamine above 1.0 μg./ml. or of ATP above 30 μg./ml. did not result in any appreciable increase in growth.

TABLE I

Comparative Response of Several Strains of Hemophilus piscium *to Various Additions to the Basal Medium*

Addition to basal medium	Amount/10 ml.	Per cent light transmission *H. piscium* (Strain)			
		XI	XIII	XIX	XX
None		100	100	100	100
Thiamine	0.1–10 mg.	100	100	100	100
+ K_2HPO_4	2.0 mg.	100	100	100	100
Adenosine triphosphate[a]	300 μg.	76	67	68	72
Diphosphothiamine[b]	100 μg.	65	61	61	62
+ Inactive enzyme (Taka-diastase)				62	59
+ Active enzyme				96	98
"Fish peptone"	0.5 ml.			53	55
+ inactive enzyme				56	59
+ active enzyme				84	81

[a] Schwarz Laboratories, New York, N. Y.

[b] Merck & Co., Rahway, N. J.

The effect of phosphatase cleavage on synthetic diphosphothiamine and "fish peptone" by treatment with Taka-diastase[4] was determined using a method similar to that of Cheldelin *et al.* (2). The activity of diphosphothiamine was almost completely eliminated after incubation with the active enzyme preparation; approximately 35% of that of the "fish peptone" was lost. The latter may indicate that diphosphothiamine present in the natural material is firmly bound and not easily attacked. This observation has been suggested in other studies (3,4).

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[3] The preparation of "fish peptone" has been described previously (1).

[4] Parke, Davis & Co., Detroit, Michigan.

With organisms in which diphosphothiamine has been shown to promote growth, usually thiamine was also active (4,5,6). It would appear that this is not true of *H. piscium*. Concentrations of thiamine of 1–100 mg.-% in the final medium would not support growth.

The ability of diphosphothiamine and ATP to initiate growth is strikingly similar to that reported by Tamura and Fleming (7) for *Bacterium tularense*. These authors found that heaviest growth was obtained in the presence of ATP.

Summary

In the present report, approximately thirty times as much adenosine triphosphate (ATP) was required to produce the maximum growth response of *H. piscium* as compared with diphosphothiamine. The activity may be due to ATP itself; however, the possibility that this substance may be active by virtue of the presence of small amounts of a contaminating substance such as diphosphothiamine should not be overlooked.

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THE EFFECT OF SULFAMERAZINE ON THE ERYTHROCYTE AND HEMOGLOBIN CONTENT OF TROUT BLOOD

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INTRODUCTION

THE DISCOVERY, at Leetown in 1945, of the effectiveness of sulfamerazine in the treatment of furunculosis in trout (1, 2), and the consequent widespread use of this drug for this purpose, made it important to learn the effects of this sulfonamide on trout. Accordingly an experiment was run to test the effects of various dosage rates, from approximately the minimum effective rate to one greatly in excess of the highest rate recommended.

The daily dosage rate originally recommended (2) was 8 grams per 100 pounds of fish. Later it was found that a lighter rate was sufficient and that a 4-gram rate was about as effective as the 6-gram rate subsequently recommended (3, 4, 5). The dosage rates used in this experiment were 0, 5, 10 and 15 grams of sulfamerazine per day per 100 pounds of fish.

The duration of treatment originally recommended was three weeks. In this experiment sulfamerazine was administered through more than twice this period.

In the original experiment (1, 2) the species of trout used was the Eastern brook trout, *Salvelinus fontinalis*, a species very susceptible to furunculosis. This experiment, described in part by Gutsell and Snieszko (12), included two other species: the brown trout, *Salmo trutta* or *Salmo fario*, generally less susceptible; and the rainbow trout, *Salmo gairdnerii*, which only occasionally suffers noticeable loss from this disease.

The test using brook and rainbow trout was run in 1946; that using brown trout in 1947. Erythrocyte counts and hemoglobin measurements were made only in 1947 and therefore could include only the brown trout.

With rainbow trout, growth was not affected even by the heaviest dosage. With brook trout, growth was much reduced only by the heavier dosage rates; with brown trout, even by the lightest rate. The reduced growth in brook and brown trout appeared to be due to reduced food consumption due to dislike of the taste of the food containing the drug. In this and in other experiments run at Leetown, there was not any mortality attributable to the use of sulfamerazine.

METHODS AND PROCEDURE

As noted above, the daily sulfamerazine dosage rates were 0, 5, 10 and 15 grams per 100 pounds of fish (0, 11, 22, and 33 grams per 100 kilograms). The drug was administered by being mixed very thoroughly with the food. Except for the 0-rate, all food used in the experiment contained the drug. Treatment was continued through 49 days.

Five pounds of brown trout from one large pool were placed in each of 8 adjacent upper troughs in the hatchery. Each of the 4 treatments was assigned to 2 troughs by random selection, so that the test was run in duplicate and was fully randomized.

The hemoglobin measurements were made after 35 days of treatment; the erythrocyte counts, after 42 days. A Helige hemometer was used for the hemoglobin measurements and a Spencer Bright-line counting chamber for erythrocyte counts. The usual technique for these operations was followed, except that Dr. S. F. Snieszko, who made the measurements and counts, used his *cold method* (Pipettes kept at a low temperature and fish placed in ice-water, to prevent the clotting which is the bane of such work with trout blood). For the erythrocyte counts, a 1–100 dilution was used.

The fish used for the hemoglobin measurements and red cell counts were taken at random from each trough by means of a dip net.

For hemoglobin measurements, 10 fish were taken from each trough, or 20 fish for each treatment. For erythrocyte counts, only half this number of fish were used, but two counting chambers (*a* and *b*) were filled from each fish. Thus there were 20 erythrocyte counts and 20 hemoglobin measurements for each treatment.

THE DATA AND THEIR ANALYSIS

The average hemoglobin and erythrocyte contents are shown in Figure 1; the hemoglobin measurements and erythrocyte counts in Tables 1 and 3. Hemoglobin is expressed as grams per 100 milliliters of blood. Each erythrocyte count in Table 3 is the sum of the counts for 5 secondary squares. Because the dilution was 1–100, each count in Table 3 (or each average of such counts) should be divided by 2 before the 4 zeros (0, 000) are added to give the number of erythrocytes per cubic millimeter of blood.[1]

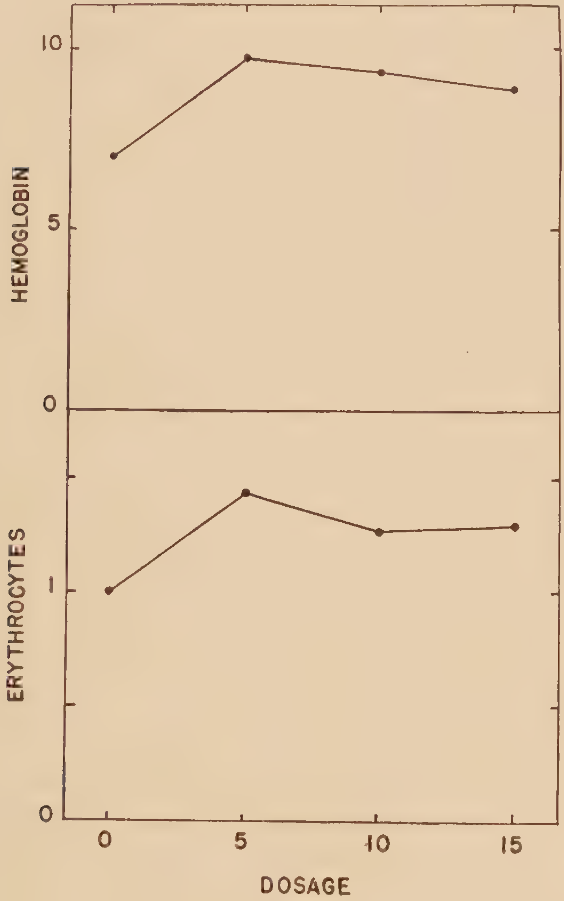

FIGURE 1.
Hemoglobin (grams per 100 ml.) and erythrocytes (millions per cu. mm.) in the blood of brown trout after 35 (hemoglobin) and 42 (erythrocytes) days of treatment at the daily dosage rates of 0, 5, 10 and 15 grams of sulfamerazine per 100 pounds of fish. Each point represents the average of 20 determinations.

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[1] Each count is the number of red cells in 5 secondary squares of the counting chamber. The volume of the diluted blood in the 5 secondary squares is 1/50 of a cubic millimeter. Therefore, the estimated number of red cells in a cubic millimeter of the diluted blood is 50 times the count. If the dilution was 1/100, the estimated number of erythrocytes per cubic millimeter of blood is 5,000 (100 × 50) times the count. This multiplication is most conveniently done by dividing the count by 2 and adding 4 zeros (0,000; equivalent to multiplying by 10,000).

TABLE 1
MEASUREMENTS OF HEMOGLOBIN (GRAMS PER 100 ML.) IN THE BLOOD OF BROWN TROUT AFTER 35 DAYS OF TREATMENT AT THE DAILY RATES OF 0, 5, 10 AND 15 GRAMS OF SULFAMERAZINE PER 100 POUNDS OF FISH. TWO TROUGHS, *A* AND *B*, FOR EACH TREATMENT; 1 MEASUREMENT FROM EACH OF 10 FISH FROM EACH TROUGH.

Fish no.	Treatment 0		Treatment 5		Treatment 10		Treatment 15	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*
1	6.7	7.0	9.9	9.9	10.4	9.9	9.3	11.0
2	7.8	7.8	8.4	9.6	8.1	9.6	9.3	9.3
3	5.5	6.8	10.4	10.2	10.6	10.2	7.2	11.0
4	8.4	7.0	9.3	10.4	8.7	10.4	7.8	9.0
5	7.0	7.5	10.7	11.3	10.7	11.3	9.3	8.4
6	7.8	6.5	11.9	9.1	9.1	10.9	10.2	8.4
7	8.6	5.8	7.1	9.0	8.8	8.0	8.7	6.8
8	7.4	7.1	6.4	10.6	8.1	10.2	8.6	7.2
9	5.8	6.5	8.6	11.7	7.8	6.1	9.3	8.1
10	7.0	5.5	10.6	9.6	8.0	10.7	7.2	11.0
Trough sums	72.0	67.5	93.3	101.4	90.3	97.3	86.9	90.2
Treatment sums	139.5		194.7		187.6		177.1	
means	6.98		9.74		9.38		8.86	
Total	698.9							

Analyses of variance of the data are given in Tables 2 (hemoglobin) and 4 (erythrocytes). The higher hemoglobin and erythrocyte contents of the blood of fish given sulfamerazine are found to be highly significant (*F* for treatments above the 0.1 percent probability points). For the erythrocyte data, this applies not only to the counts but also to the square root and logarithmic transformations (see bottom of Table 4). Neither transformation changed the picture.

In the breakdown of the three degrees of freedom for treatment, for each degree *F* is above the 5 percent probability point, and for all but one degree (third degree, hemoglobin) above the one precent probability point.

To get at this another way, the values for the 5-gram rate were compared with those for each of the others. For hemoglobin the comparisons were as follows: 5-gram rate *vs.* 0-rate, $F = 49.11$; 5-gram rate *vs.* 10-gram rate, $F = 0.81$; 5-gram rate *vs.* 15-gram rate, $F = 4.99$

TABLE 2
ANALYSIS OF VARIANCE OF HEMOGLOBIN DATA.

Source of variation	Degrees of freedom	Sums of squares	Mean squares	F	Probability Points		
					5%	1%	0.1%
Total	79	209.48					
Treatments .	3	90.56	30.19	19.48	2.74	4.08	6.09
(1st°) Linear .	1	27.93	27.93	18.02	3.98	7.01	11.87
(2nd°) Quadratic . . .	1	53.96	53.96	34.81	3.98	7.01	11.87
(3rd°) Cubic .	1	8.67	8.67	5.59	3.98	7.01	
Between troughs treated alike	4	7.29	1.82	1.17	2.50		
Between fish in same trough	72	111.64	1.55				

TABLE 3
ERYTHROCYTE COUNTS[1] (5 SECONDARY SQUARES; DILUTION, 1–100) FROM BROWN TROUT AFTER 42 DAYS OF TREATMENT AT DAILY RATES OF 0, 5, 10 AND 15 GRAMS OF SULFAMERAZINE PER 100 POUNDS OF FISH. TWO TROUGHS, *A* AND *B*, FOR EACH TREATMENT; 5 FISH FROM EACH TROUGH; 2 SLIDES, *a* AND *b*, FROM EACH FISH. TREATMENT MEANS SHOWN (IN PARENTHESES) AS NUMBERS PER CU. MM.

Fish no.	Treatment 0				Treatment 5				Treatment 10				Treatment 15			
	A		*B*		*A*		*B*		*A*		*B*		*A*		*B*	
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
1	213	230	166	157	296	319	310	309	339	322	196	232	278	212	287	280
2	253	231	206	185	278	258	241	270	282	285	205	186	275	311	221	243
3	195	164	245	250	345	307	272	311	236	262	252	274	186	158	331	309
4	193	203	213	181	322	372	254	237	252	209	245	216	301	281	231	244
5	191	195	198	169	248	274	266	275	263	296	249	260	223	246	292	295
Column sums .	1045	1023	1028	942	1489	1530	1343	1402	1372	1374	1147	1168	1263	1208	1362	1371
Trough sums . .	2068		1970		3019		2745		2746		2315		2471		2733	
Treatment sums	4038				5764				5061				5204			
Treatment means	201.9 (1,009,500)				288.2 (1,441,000)				253.05 (1,265,250)				260.2 (1,301,000)			
Total	20,067															

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[1] To convert counts to numbers per cubic millimeter, divide by 2 and add 0,000; thus 230/2 = 115; 115 plus 0,000 = 1,150,000. (See footnote to text).

(F .05 = 3.98). For erythrocytes: 5-gram rate *vs.* 0-rate, $F = 30.45$; 5-gram rate *vs.* 10-gram rate, $F = 5.05$; 5-gram rate *vs.* 15-gram rate, $F = 3.21$ (F .1 = 2.88, F .05 = 4.15).

In a t test, a comparison of the 5-gram rate with the 15-gram rate (hemoglobin) gave $t = 2.078$ (t .05 = 2.025).

TABLE 4
ANALYSIS OF VARIANCE OF ERYTHROCYTE COUNTS

Source of Variation	Degrees of freedom	Sums of squares	Mean squares	F[1]	Probability points		
					5%	1%	0.1%
Total	79	186,948.89					
Treatments	3	77,667.74	25,889.25	10.58	2.90	4.46	6.96
(1st°) Linear	1	19,530.06	19,530.06	7.98	4.15	7.50	13.15
(2nd°) Quadratic . . .	1	31,323.61	31,323.61	12.81	4.15	7.50	13.15
(3rd°) Cubic	1	26,814.06	26,814.06	10.96	4.15	7.50	13.15
Between troughs treated alike	4	16,954.25	4,238.56	1.73	2.67		
Between fish in same trough	32	78,267.40	2,445.86	6.93	1.74	2.20	2.6
Between samples from same fish	40	14,059.50	351.49				

[1] After square root transformation, the values found for F for treatments, troughs and fish were 11.77, 1.82, 4.37; after logarithmic transformation, 11.01, 1.61 and 4.01.

DISCUSSION

The analyses of the data strongly indicate that the higher hemoglobin and erythrocyte concentrations in the blood of the brown trout on the diets including sulfamerazine is causally connected with the presence of sulfamerazine in the diet. There is considerable indication that the higher content associated with the 5-gram drug rate is significant (see Tables 2 and 4, individual degrees of freedom for treatment, also reference in the text to tests of significance), that the 5-gram rate truly is superior in this respect (perhaps near the optimum rate) under the conditions of the experiment.

An important consideration is the relationship of the hemoglobin and red cell concentrations associated with the various treatments, including the 0-rate, to the normal concentrations. What are the normal concentrations? Schlicher (6, quoted by Wunder, 7) listed 1,140,000 erythrocytes per cubic millimeter of blood for brown trout, sensibly the same as for rainbow trout (1,100,000). Phillips (8, Fig. 1) found above 1,500,000 erythrocytes per cubic millimeter of blood from brook trout before they were put on a synthetic diet and after they were given beef liver to the extent of half of the diet. Tunison *et al*, (9) present these same findings and others showing brook trout on a straight beef liver diet with 1,176,666 red cells per cubic millimeter. Tunison *et al*, (10) reported the following yearly averages for trout on a diet of beef liver (50 percent), pork spleen (48 percent) and salt (2 percent): rainbow, 1,220,000; brook, 1,032,000; brown, 766,000 erythrocytes per cubic millimeter of blood. Phillips *et al*, (11) found the following number of red cells per cubic millimeter of blood after the trout had been 22 weeks on a diet of beef liver (98 percent) and salt (2 percent): rainbow, 1,165,000; brook, 1,186,000; brown 1,099,000. On a diet of beef spleen (98 percent) and salt, the numbers were very similar: rainbow, 1,164,000; brook, 1,181,000; and brown, 1,116,000. Schlicher (see above) gave the hemoglobin level for brown trout as 60 percent (presumably of the normal for human blood or .6(14.5) = 8.7 grams per 100 milliliters).

If it were not for the one high level, shown by Phillips (8, Fig. 1) and Tunison *et al*, (9, Chart 11), a fair assumption from the above references would be that for brook, rainbow and brown trout the normal is close to 1,000,000—1,200,000 per cubic millimeter. This is above the average for the "control" trout in this experiment, below the average for the others. If about 1,500,000 (8, 9) is normal, only the trout treated at the 5-gram rate showed an average approaching the normal red cell concentration.

Another important consideration is the probable sulfamerazine concentrations or levels obtained with the various treatment rates. For brown trout, data are available for approximately the 5-gram rate. Snieszko and Friddle (unpublished) used the daily rate of 0.1 gram of sulfamerazine per kilogram of trout (4.54 grams per 100 pounds) with this species. After a week of treatment the following levels were found: blood, 64; liver, 24; kidney, 24; muscle, 11 milligrams percent. Thereafter, the following more moderate levels (approximate) prevailed: blood, liver and kidney, 8; muscle 5. This was the only rate studied with brown trout; but with brook trout, 0.1, 0.2 and 0.3 grams per day per kilogram of trout (roughly corresponding with the 5, 10, and 15 grams per 100 pounds used in this experiment) were investigated. The following levels approximate those which prevailed after three days in gutted fish and presumably are close to the levels for the muscle: 0.1, 3; 0.2, 6; and 0.3, 7 milligrams percent. These findings indicate that the 5-gram rate is unusually effective with brown trout in producing satisfactory therapeutic sulfamerazine levels, and that the high hemoglobin and erythrocyte levels which followed prolonged treatment with sulfamerazine were associated with fairly high sulfamerazine levels in the blood and tissues.

That the sulfamerazine treatment, almost certainly accompanied by high sulfonamide blood levels, did not reduce the hemoglobin and erythrocyte concentrations is notably important; that these concentrations were increased is of great interest and of possible importance. The considerably higher concentration associated with the use of one of the three dosage rates is of additional interest.

Because prolonged sulfamerazine treatments at high dosage rates had not been accompanied or followed by any trout mortality attributable to the drug (2, 5, 12), the lack of a reduction in the concentration of hemoglobin and erythrocytes was not altogether surprising; but the increase was a great surprise and still is a puzzle. Gutsell and Snieszko (12) offered the following possible explanations: 1, some infection, apparently not furunculosis (13), causing a moderate anemia was cured or greatly reduced by sulfamerazine therapy; 2, the sulfonamide to some degree inhibited the respiratory enzymes (14) with the effect of a reduction in the oxygen supply which is (15) to increase the hemoglobin and erythrocyte concentrations; 3, sulfamerazine, instead of having an anemic effect, stimulates the production of hemoglobin and erythrocytes in trout. The writer offers a fourth possible explanation, that the diet caused a moderate anemia, and that the sulfamerazine, by reducing the consumption of food (as was observed to be the case), reduced the anemia (and growth, of course).

The clear evidence that continued dosage with sulfamerazine did not reduce the hemoglobin or erythrocyte concentrations explains in some measure why adverse effects, other than poor food consumption (apparently due to dislike of the taste of the drug) and reduced growth, have not been observed at Leetown, either in experiments or in practical application of sulfamerazine therapy for furunculosis.

The author wishes to thank Dr. C. M. Mottley for suggestions for the analysis of these data, especially the erythrocyte counts, and for reading the manuscript. Dr. S. F. Snieszko, as a collaborator in the investigation, made the erythrocyte counts and hemoglobin measurements. Mr. Saufley Friddle helped in the preparation of the diets and in feeding the trout. Messers. E. W. Surber and B. H. Hazen made hatchery troughs available and extended numerous courtesies.

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STATUS OF THE LAKE TROUT FISHERY IN LAKE SUPERIOR

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Abstract

The production of lake trout in the United States waters of Lake Superior was low (only 1,465,000 pounds) in 1879, the first year for which there is a record. Expansion of the fishery must have started soon thereafter, for the take was 3,488,000 pounds in 1885, the next year for which we have statistics, and averaged 3,416,000 pounds in 1885-1892. The years after 1892 can be divided readily into three general periods with average yields as follows: 1893-1907—4,599,000 pounds; 1908-1925—2,168,000 pounds; 1926-1949—3,049,000 pounds. A take of 3 million pounds can be held as "normal" in the modern fishery. During the three periods just listed the percentage contributions of the individual states to the United States total (as computed from the averages for individual periods) ranged from 65.1 to 71.5 for Michigan, 17.5 to 25.6 for Wisconsin, and from 9.3 to 11.0 for Minnesota.

In the Canadian (Province of Ontario) waters of Lake Superior the average annual output of lake trout rose from 309,000 pounds in 1871-1882 to 900,000 pounds in 1883-1893, 1,567,000 pounds in 1894-1903, and 2,189,000 pounds in 1904-1918. This last period of relatively high yield was followed by two intervals of successively lower average catches—1,691,000 pounds in 1919-1929 and 1,395,000 pounds in 1930-1949.

For the combined United States and Canadian waters of Lake Superior the general trends in the production of lake trout can be described by the following averages: 1879—1,653,000 pounds; 1885-1892—4,325,000 pounds; 1893-1907—6,236,000 pounds; 1908-1949—4,403,000 pounds.

The short-term fluctuations of production during the more recent years give evidence of periodicity in the output of lake trout in Michigan, Ontario, and in the entire lake. Furthermore, these periodic fluctuations tended to be similar in Michigan and Ontario waters. The coefficient of correlation (r) between

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production in Michigan and Ontario in 1920-1949 (after elimination of trend in the statistics for both areas) had the significant value of 0.456. This correlation suggests that Michigan and Ontario fishermen exploit a common stock or stocks subject to similar fluctuations.

Statistics on the production of lake trout in 5 of the 6 statistical districts of the State of Michigan waters of Lake Superior (see Fig. 2 for boundaries of the districts) in 1885 suggest that in most areas the fishery was then in the process of development. Even in 1891-1908 when the general level of production was high, there is evidence that during certain periods the catch in some areas was influenced strongly by factors (such as accessibility to market) other than the natural productivity of the waters. Comparisons of the average annual output of lake trout in the individual districts in 1891-1908 and 1929-1943 (the base period for our modern statistical analysis) reveal an enormous decrease in the Whitefish Bay region (S-6) from 916,000 pounds in 1891-1908 to only 177,000 pounds in 1929-1943, a substantial drop (from 655,000 pounds to 385,000 pounds) in the Marquette-Munising area (S-4), and a small decrease (from 141,000 pounds to 138,000 pounds) in the Black River-Ontonagon district (S-2). Among the remaining districts the average yearly take increased from 322,000 pounds in 1891-1908 to 354,000 pounds in 1929-1943 at Isle Royal (S-1), from 428,000 pounds to 501,000 pounds in the Grand Marais district (S-5), and from 422,000 pounds to 506,000 pounds in the Keweenaw area (S-3). These changes in the catch resulted in a westward shifting of production centers. Districts S-1, S-2, and S-3 which together contributed only 30.7 percent of the 1891-1908 catch accounted for 48.4 percent of the take in 1929-1943.

The 1929-1949 production in all districts exhibited periodic fluctuations that were characterized by peaks in the middle 1930's and middle 1940's.

The indices of abundance or availability as computed from records of the catch of lake trout per unit of fishing effort showed periodic fluctuations in all districts of the State of Michigan waters similar to those of production (the peaks and the intervening minima fell a little earlier in the curves of abundance than in the production curves). For the combined districts the abundance of lake trout, expressed as a percentage of the 1929-1943 mean, stood at 108 in 1929, dropped to 100 in 1931, rose to a 21-year high of 137 in 1934, decreased to 80 in 1940, increased again to 107 in 1944 and then fell to the 21-year low of 65 in 1949 (this last decline was interrupted by a small increase in 1947).

The 1929-1949 fluctuations in abundance were similar in the 5 mainland districts (S-2 through S-6). The coefficients of correlation (r) were significant for all 10 pairings and those for the 4 easterly districts (S-3 through S-6) were extremely high ($p < 0.001$ for all 6 values). Thus we have evidence that the fishermen along the mainland exploit common stocks or stocks in which the factors controlling availability are the same or subject to closely similar fluctuations. The fluctuations in abundance in S-1 were correlated significantly ($p < 0.05$) with those in S-2 but otherwise appeared to be independent of conditions along the mainland.

The distinctly cyclic fluctuations that characterized the statistics on production and abundance were much less apparent in the 1929-1949 data on fishing intensity in the State of Michigan districts. In districts S-3, S-4, and S-5 a possible tendency toward a cyclic fluctuation seems to have been obscured by a long-term upward trend that was becoming stronger toward the end of the 21-year period. For the combined districts the level of fishing pressure was consistently high after 1943. Over the 6-year period, 1944-1949, fishing intensity expressed as a percentage of the 1929-1943 mean averaged 142; for the most recent 4 years, 1946-1949 the average intensity index was 151.

On the whole, the 1929-1949 production of lake trout in the State of Michigan waters of Lake Superior was unreliable as an indicator of changes in abundance. The coefficient of correlation between the fluctuations of catch and abundance was, to be sure, positive and significant in S-1 ($p < 0.05$) and

S-6 ($p < 0.01$), but in the remaining districts and for the combined districts the values of the coefficient were far below the level of significance.

The failure of production to serve better as an indicator of changes in abundance can be attributed to the negative correlation that existed between abundance and fishing intensity (values of r highly significant in every district but S-6 and for the combined districts). The relationship suggests that fishermen have increased their fishing pressure in order to maintain their production during the recent years of declining abundance.

The condition of the lake trout fishery of the State of Michigan waters of Lake Superior must be termed unhealthy and the outlook for the future is not good. Production in 1949 stood at 106 percent of the 1929-1943 mean, but this level of yield was made possible only by fishing intensity that was 162 percent of average; the abundance index in 1949 was only 65. Certainly the stocks of lake trout are in a poor state to withstand the threatened inroads of sea lampreys which have been taken from all parts of Lake Superior and are known to have established spawning runs at least as far west as the Keweenaw Peninsula.

INTRODUCTION

Coincident with the spread and increase in the abundance of the parasitic sea lamprey (*Petromyzon marinus*) in Lakes Huron and Michigan the stocks of lake trout (*Salvelinus namaycush*) declined to such a low level as to bring an end to commercial operations directed specifically toward the capture of that species. It is the considered opinion of the investigators of the staff of Great Lakes Fishery Investigations that depredations of the lamprey have been the major, and in all probability the only significant, contributing factor to the catastrophes that have overtaken both lakes. We concede readily that absolute proof of our belief is lacking. On the other hand, the extensive evidence available permits us no other view. A critical evaluation of this evidence does not come within the scope of this paper. Of primary significance in the array, however, are the statistical records (Hile, 1949; Hile, Eschmeyer, and Lunger, 1951) which demonstrate conclusively that overfishing was not, as frequently has been alleged, the cause of the failure of the lake trout fishery in either the United States waters of Lake Huron or the State of Michigan waters of Lake Michigan.

The disappearance of the lake trout fishery in Lakes Huron and Michigan leaves Lake Superior as the only important center of commercial production of the species in the United States, and even in this last stronghold the stocks are in awful danger of early destruction. As yet we have no evidence of extensive damage by the sea lamprey in Lake Superior. On the other hand, adult sea lampreys have been captured in all parts of the lake and the presence of spawning runs has been established as far west as the Keweenaw Peninsula. Since each new lake presents a new and different environment, we cannot attempt to predict the extent or rate of increase in the abundance of sea lampreys in Lake Superior. Conceivably this, the most northerly and the coldest of the Great Lakes, may prove less hospitable than did Lakes Huron and Michigan. It is equally conceivable, unfortunately, that the lake trout fishery may collapse as rapidly in Lake Superior as it did in Lake Michigan where the commercial take dropped more than 90 percent in a brief span of 5 years.

The fisheries of Lake Superior are so constituted that the disappearance of the lake trout would mean an end to the fishing industry as it has existed in the past. In support of this statement, it may be pointed out that during the 5 years 1945-1949 the lake trout, although contributing only 14 to 20 percent of the total production in the United States waters of Lake Superior, brought such high prices as to account for 51 to 60 percent of the total value of the catch. Not only would the disappearance of the lake trout entail the loss of more than half of the cash income of Lake Superior fishermen; it would force discontinuation of much of the fishing now carried on for the capture of lake herring (*Leucichthys artedi*), the principal species from the standpoint of production (72 to 77 percent of the take in 1945-1949, but, because of the low price, only 20 to 32 percent of the value). The great bulk of the lake herring catch is taken within the space of a few weeks in late November and early December. At other times of the season, fishing is directed largely toward the capture of the lake trout. With that species gone, therefore, operations during much of the season would have to be discontinued. It is to be questioned whether many fishermen could afford to maintain their boats, houses, and equipment for the short-term fishery for the cheap lake herring. In all probability most of them would be forced to abandon fishing altogether and turn to other means of livelihood. At best, fishing for lake herring would become small-scale and casual, with most of the present high production lost.

The continuation of fishing for lake whitefish (*Coregonus clupeaformis*), the third important fish in Lake Superior (4 to 7 percent of the catch and 12 to 23 percent of the value in 1945-1949) might be possible for a time in the local areas in which the species is abundant, but even this fishery would be handicapped by the loss of the lake trout ordinarily captured along with the whitefish. Furthermore, experiences in Lakes Huron and Michigan have demonstrated that the whitefish is in no sense immune to attacks by the sea lamprey and that predation on the whitefish increases as the lake trout becomes less plentiful.

In Lake Superior, therefore, we face the prospect of losing the greater part of the present production of fish — a production that normally falls between 15 and 20 million pounds. This loss is not inconsiderable at a period when the maintenance of food production bids fair to become a question of national importance. Furthermore, the effects of the loss on the economies of the many local communities that depend primarily on the fisheries would be disastrous.

Materials and Methods

Statistics on the commercial production of lake trout in Lake Superior through 1940 have been adapted from Gallagher and Van Oosten (1943).

TABLE 1.—*Production (thousands of pounds) of lake trout in the commercial fisheries of Lake Superior, 1871-1949.*

Year	State			U. S. total	Canada (Ontario)	Grand total
	Minnesota	Wisconsin	Michigan			
1871	....	....	....	....	169	....
1872	....	....	....	....	227	....
1873	....	....	....	....	300	....
1874	....	....	....	....	337	....
1875	....	....	....	....	191	....
1876	....	....	....	....	679	....
1877	....	....	....	....	607	....
1878	....	....	....	....	98	....
1879	....	....	....	1,465	189	1,653
1880	....	....	....	....	313	....
1881	....	....	....	....	181	....
1882	....	....	....	....	416	....
1883	....	....	....	....	852	....
1884	....	....	....	....	646	....
1885	1,376	785	1,327	3,488	912	4,400
1886	....	....	....	....	842	....
1887	....	....	....	....	703	....
1888	....	....	....	....	971	....
1889	1,099	430	1,838	3,367	1,020	4,387
1890	138	356	2,119	2,613	692	3,306
1891	....	....	2,729	....	1,077	....
1892	....	601	1,998	....	1,056	....
1893	619	1,100	2,622	4,342	1,129	5,471
1894	....	1,102	2,506	....	1,543	....
1895	....	1,500	2,226	....	1,378	....
1896	....	2,000	2,459	....	1,529	....
1897	394	780	2,620	3,794	1,543	5,337
1898	....	....	2,675	....	1,490	....
1899	247	709	2,668	3,625	2,183	5,808
1900	....	....	2,575	....	1,332	....
1901	....	....	3,039	....	1,537	....
1902	....	....	2,478	....	1,377	....
1903	489	1,048	4,055	5,592	1,760	7,352
1904	....	....	4,330	....	2,226	....
1905	....	....	4,101	....	1,984	....
1906	....	....	3,617	....	1,971	....
1907	400	....	2,916	....	1,575	....
1908	215	382	2,306	2,903	1,968	4,871
1909	....	427	....	....	3,156	....
1910	....	260	....	....	3,966	....
1911	....	505	880	....	1,725	....
1912	....	521	938	....	1,588	....
1913	150	856	1,380	2,386	1,842	4,228
1914	105	629	942	1,676	1,576	3,252
1915	86	511	776	1,373	3,610	4,983
1916	137	586	1,455	2,178	1,522	3,699
1917	125	435	1,424	1,983	1,810	3,793
1918	223	441	1,662	2,326	2,319	4,645
1919	242	470	2,752	3,463	1,471	4,934
1920	238	458	1,319	2,016	1,108	3,124
1921	383	501	1,240	2,124	1,176	3,300
1922	236	562	1,376	2,175	1,486	3,660
1923	253	482	1,165	1,901	1,958	3,859
1924	371	557	1,637	2,565	1,711	4,276
1925	345	475	1,834	2,655	1,868	4,522
1926	333	441	2,506	3,280	1,966	5,246
1927	324	534	2,194	3,051	2,197	5,248
1928	391	291	2,280	2,962	1,914	4,876
1929	322	558	1,924	2,804	1,747	4,551
1930	294	475	1,720	2,489	1,530	4,019
1931	536	495	1,961	2,993	1,328	4,321
1932	532	564	1,971	3,067	1,124	4,191
1933	227	560	1,706	2,493	968	3,461
1934	270	611	2,493	3,374	1,261	4,634
1935	379	502	2,596	3,476	1,518	4,994
1936	393	520	2,319	3,233	1,596	4,829
1937	354	440	2,291	3,085	1,699	4,784
1938	463	520	2,184	3,167	1,668	4,835
1939	349	462	1,934	2,744	1,307	4,052
1940	321	513	1,843	2,677	1,261	3,938

TABLE 1.—*Continued*

Year	State			U. S. total	Canada (Ontario)	Grand total
	Minnesota	Wisconsin	Michigan			
1941	353	630	1,871	2,854	1,298	4,153
1942	277	659	2,023	2,959	1,361	4,320
1943	347	618	2,089	3,053	1,323	4,376
1944	332	708	2,700	3,740	1,553	5,292
1945	234	573	2,562	3,369	1,479	4,848
1946	316	534	2,594	3,444	1,531	4,975
1947	219	518	2,226	2,964	1,286	4,250
1948	240	553	2,161	2,954	1,447	4,401
1949	270	514	2,181	2,966	1,356	4,322

Data for United States waters in years after 1940 were compiled in the Great Lakes office of the Fish and Wildlife Service (Michigan) or supplied by state conservation departments (Wisconsin and Minnesota); catch figures for Canadian waters in these same years were obtained from published reports of the Ontario Department of Lands and Forests (formerly the Game and Fisheries Department) or supplied privately by that organization.

Catch statistics for local districts in the State of Michigan waters of Lake Superior in 1885 were taken from Smith and Snell (1891); those for 1891-1908 were compiled (with W.P.A. assistance) from original records made available by the Michigan Department of Conservation. Detailed information on the production and abundance of lake trout and on the intensity of the fishery for the species in the same statistical areas, 1929-1949, was derived from reports of commercial fishing submitted each month by every commercial operator licensed by the State of Michigan, and turned over to us for analysis by the Department of Conservation.

Descriptions of methods employed for the analysis of commercial fishery statistics in the State of Michigan waters of the Great Lakes and examples of the application of the statistics to various fishery problems can be found in papers by: Hile (1937, 1949); Hile and Jobes (1941); Van Oosten, Hile, and Jobes (1946); Hile, Eschmeyer, and Lunger (1951).

Illustrations published in this article were prepared by Mr. Howard J. Buettner.

TRENDS IN THE PRODUCTION OF LAKE TROUT IN LAKE SUPERIOR, 1871-1949

Comments on the trends in the production of lake trout in Lake Superior (Table 1) will be based largely on the averages for selected periods of years (Table 2). It is not intended to imply through this division into periods that the level of the take was stable in any of them. On the contrary, the inspection of Table 1 reveals wide variation in the catch

TABLE 2.—*Average production (thousands of pounds) of lake trout in various areas of Lake Superior in certain periods of years and percentage distribution of the United States catch among the different states.*

Period of years	Item	United States				Canada (Ontario)		Entire lake	
		Minnesota	Wisconsin	Michigan	Total[1]	Period of years	Production	Period of years	Production[1]
1879	Production	....	....	....	1,465	1871—1882	309	1879	1,653
1885—1892	Production	871	543	2,002	3,416	1883—1893	900	1885—1892	4,325
	Percentage	25.5	15.9	58.6	....				
1893—1907	Production	430	1,177	2,992	4,599	1894—1903	1,567	1893—1907	6,236
	Percentage	9.3	25.6	65.1	....	1904—1918	2,189	1908—1949	4,403
1908—1925	Production	222	503	1,443	2,168	1919—1929	1,691	....	....
	Percentage	10.2	23.2	66.6	....				
1926—1949	Production	336	533	2,180	3,049	1930—1949	1,395	....	....
	Percentage	11.0	17.5	71.5	....	....	....	....	....

[1] The totals are the sums of the means as determined for the states (and province in the figures for the entire lake) individually from all data available for each area in the indicated period.

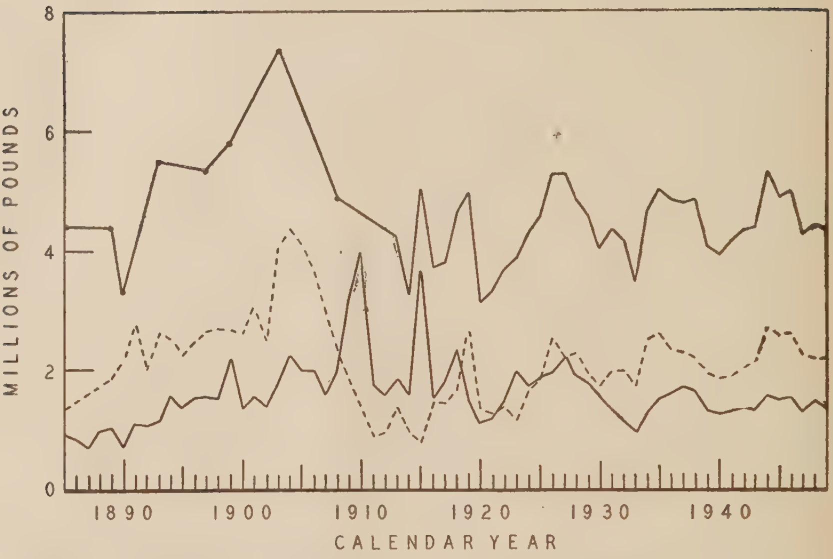

FIGURE 1.—Production of lake trout in Lake Superior, 1885-1949. Province of Ontario, lower solid line; State of Michigan, broken line; entire lake, upper solid line. In the upper curve heavy dots show the scattered individual years prior to 1913 in which catch records were available for the entire lake.

in all periods and a strong tendency toward cyclic fluctuations within some. It is believed, nevertheless, that the data of Table 2 serve adequately the purpose of describing the changes in the general level of yield that have taken place.

United States production.—In 1879, the first year for which we have a record of the output of lake trout in the United States waters of Lake Superior, the take was only 1,465,000 pounds. Presumably the fishery was then still in the earlier stages of development. Data are lacking on the 1879 yield of lake trout in the individual states.

The average production of 3,416,000 pounds in 1885-1892 (see footnote to Table 2 concerning the method of computing the average) was 2.3 times that in 1879. Although the take varied considerably in all states — 1,327,000 to 2,729,000 pounds in Michigan (Fig. 1); 356,000 to 785,000 pounds in Wisconsin; 138,000 to 1,376,000 pounds in Minnesota — the relative fluctuation was by far the greatest in the last named state. Indeed, the abrupt drop from more than a million pounds in 1885 and 1889 to only 138,000 pounds in 1890 gives cause for skepticism as to the reliability of the Minnesota statistics for those years. Michigan contributed well over half (58.6 percent) of 1885-1892 production of lake trout in the United States waters of Lake Superior with Minnesota ranking second (25.5 percent) and Wisconsin third (15.9 percent). If we were to assume that the percentage contribution of Minnesota amounted to only 10 percent (a figure supported by the data for later periods), the catch from that state in 1885-1892 could be estimated at 283,000 pounds; the average for all United States waters would then become 2,828,000 pounds and the percentage contributions of Wisconsin and Michigan would be 19.2 and 70.8 respectively.

The average catch of lake trout in 1893-1907 (4,599,000 pounds) was 1,183,000 pounds greater than that for 1885-1892. The rise can be traced entirely to Michigan and Wisconsin where increases of 990,000 and 634,000 pounds, respectively, exceeded by far the decline of 441,000 pounds in Minnesota. The decrease in the take in Minnesota was accompanied by a decline from 25.5 to 9.3 percent in the contribution of that state to the United States total. At the same time the percentages increased from 15.9 to 25.6 in Wisconsin and from 58.6 to 65.1 in Michigan. The conflict of trends in Minnesota as compared to Michigan and Wisconsin lends additional support to the skepticism expressed in the preceding paragraph concerning the reliability of the Minnesota statistics for the 1885-1892 period.

The variations of production in the individual states in 1893-1907 were also large — 247,000 to 619,000 pounds in Minnesota; 709,000 to 2,000,000 pounds in Wisconsin; 2,226,000 to 4,330,000 pounds in Michigan — but were not of a character to raise suspicion as to the dependability of the statistics. The Michigan data, which are continuous through the period, give a suggestion of a cyclic fluctuation toward the end of the interval, with a maximum in 1904.

Statistics were available for all three states in only 4 of the 15 years of the 1893-1907 period. The extremes of 5,592,000 pounds in 1903 and 3,625,000 pounds in 1899, therefore, probably are not the true maximum and minimum for the interval.

All three states contributed toward the decline of 2,431,000 pounds or 52.9 percent from 4,599,000 pounds in 1893-1907 to 2,168,000 pounds in 1908-1925. The actual and percentage decreases for the individual states were: Minnesota—208,000 pounds, 48.4 percent; Wisconsin—674,000 pounds, 57.3 percent; Michigan—1,549,000 pounds, 51.8 percent. As would be expected from the close similarity among the relative decreases, the percentage contributions of the states to the total changed but little (increases from 9.3 to 10.2 percent and 65.1 to 66.6 percent in Minnesota and Michigan, respectively; decrease from 25.6 to 23.2 percent in Wisconsin).

The ranges of fluctuation in production in the individual states in 1908-1925 were large — 86,000 to 383,000 pounds in Minnesota; 260,000 to 856,000 pounds in Wisconsin; 776,000 to 2,752,000 pounds in Michigan — but again the nature of the variation was not such as to throw doubt on the dependability of the data. Despite the irregularity of the variations of the catch, some indications of cyclic fluctuations are detectable. It might be held, for example, that 1921 in Minnesota, 1913 in Wisconsin, and 1919 in Michigan were peak years in roughly cyclic fluctuations.

Of the 14 years in the 1908-1925 interval for which there are United States totals, the take exceeded 3 million pounds in one (3,463,000 pounds in 1919), was between 2 and 3 million pounds in 9, and fell below 2 million pounds in 4 (smallest yield, 1,373,000 pounds in 1915). These small catches are in strong contrast with those of the preceding period when all four totals were above 3 million pounds and one (that for 1903) exceeded 5½ million pounds.

The average production of lake trout increased in all three states from 1908-1925 to 1926-1949. The actual and percentage increases were: Minnesota—114,000 pounds, 51.4 percent; Wisconsin—30,000 pounds, 6.0 percent; Michigan—737,000 pounds, 51.1 percent. For all United States waters the rise amounted to 881,000 pounds or 40.6 percent. The relatively small increase in Wisconsin led to a decrease in the percentage contribution of that state to the United States total from 23.2 in 1908-1925 to 17.5 in 1926-1949; at the same time these percentages rose from 10.2 to 11.0 in Minnesota and from 66.6 to 71.5 in Michigan.

The 1926-1949 means of 336,000, 533,000, and 2,180,000 pounds for Minnesota, Wisconsin, and Michigan, respectively, and the United States average of 3,049,000 pounds can be accepted as the "modern normal" for Lake Superior. In round figures a take of 3 million pounds of lake trout per year is to be expected in the United States waters of Lake Superior under present-day conditions. Although the total range in the United States catch was fairly large (from 2,489,000 pounds in 1930 to 3,740,000 pounds in 1944 — range of 1,251,000 pounds) the catch deviated from the mean by less than 250,000 pounds in 15 of the 24 years. The ranges of production in the individual states were: Minnesota—219,000 to 536,000 pounds; Wisconsin—291,000 to 708,000 pounds; Michigan—1,706,000 to 2,700,000 pounds.

The catch statistics for the State of Michigan waters reveal a distinct periodicity in the fluctuations of production in 1926-1949. Extended comments on these fluctuations need not be offered here since the figures for most of the period (1929-1949) will be discussed in detail in the next section. Some evidence for cyclic fluctuations is to be found in the statistics for Minnesota and Wisconsin but the periods are less clearly defined than are those in the Michigan data. Cyclic fluctuations are to be noted also in the United States totals. The periods corresponded reasonably well with those for the Michigan statistics—a situation to be expected since Michigan contributed 71.5 percent of the total 1926-1949 output.

Canadian (Province of Ontario) production.—The early period 1871-1882 was one of erratically variable but generally low yields. The mean for the interval was 309,000 pounds and the range was from 98,000 pounds in 1878 to 679,000 pounds in 1876. The fishery obviously was in the early stages of development in 1871-1882.

The expansion of the lake trout fishery in the Canadian waters of Lake Superior seems to have continued through 1883-1893 (see Fig. 1

for graph of production in 1885 and later) during which period the trend of production was definitely, if irregularly, upward. This trend carried the output to more than a million pounds for the first time in 1889; the figure was exceeded again in 1891 and succeeding years. The average take in 1883-1893 (900,000 pounds) was nearly three times that of 1871-1882.

The average production in 1894-1903 (1,567,000 pounds) was 667,000 pounds above that for 1883-1893. The catch did not drop below 1,332,000 pounds (the figure for 1900) and in one year it was above 2 million (2,183,000 pounds in 1899). The fluctuations, though considerable, lacked the upward trend that characterized the preceding period.

The year 1904 introduced a 15-year interval in which the Canadian catch of lake trout in Lake Superior was at a higher level than in any earlier or later period. The average take of 2,189,000 pounds was 622,000 pounds above that for 1894-1903. Much of the increase can be traced to the three exceptional years (1909, 1910, and 1915) in which the output exceeded 3 million pounds (the catch of 3,966,000 pounds in 1910 was the record high for the Ontario waters of Lake Superior). If these three years are excluded, the mean for the period is reduced to 1,842,000 pounds and the increase over 1894-1903 to 275,000 pounds. Further indication of the effect of these three exceptional years is found in the circumstance that the catch was below the 15-year mean — indeed was less than 2 million pounds — in 10 years. The lowest take for the period was 1,522,000 pounds in 1916.

The average yield of lake trout in the Ontario waters of Lake Superior in 1919-1929 (1,691,000 pounds) was a half million (498,000) pounds below that of 1904-1918. The catch was lowest in the earlier years of the period (less than 1½ million pounds in 1919-1922 — minimum of 1,108,000 pounds in 1920). During the last 7 years the take was consistently above 1½ million pounds, and in 1927 it amounted to 2,197,000 pounds, the maximum for the period.

The output of lake trout in Ontario in 1930-1949 fluctuated about the still lower level of 1,395,000 pounds — 296,000 pounds less than the mean for 1919-1929 and 794,000 pounds below the average for 1904-1918. The catch in 1930-1949 was characteristically between 1 and 1½ million pounds (12 of 20 years). It fell below a million pounds in one year (968,000 pounds in 1933) and was more than 1½ million pounds in 7 years. The maximum yield was 1,699,000 pounds in 1937. During both of the more recent periods, 1919-1929 and 1930-1949, the production of lake trout in the Ontario waters of Lake Superior exhibited a tendency toward periodic fluctuations.

Production of the entire lake. — Because of gaps in the United States data, totals are available for the entire lake for only scattered years prior to 1913. (See Fig. 1 for a graph of the production in 1885-1949.)

In 1879, the first year for which we have a total, low catches in both the United States and Canada led to a combined take of only 1,653,000 pounds for the lake.

The level of yield was distinctly higher in 1885-1892, when the production ranged from 3,306,000 pounds in 1890 to 4,400,000 pounds in 1885 and averaged 4,325,000 pounds (see footnote to Table 2 concerning computation of average). This mean was 2,672,000 pounds above the figure for 1879.

The period 1893-1907 was one of rather consistently high production. The catch of 7,352,000 pounds in 1903 is the highest for which we have a record (the figures for Michigian and Ontario suggest strongly that the take may have been even higher in 1904 and 1905) and in each of three other years for which there is a total the output exceeded 5 million pounds (minimum of 5,337,000 pounds in 1897). The average for the 15 years as estimated from all available statistics was 6,236,000 pounds or 1,911,000 pounds greater than that for 1885-1892.

Despite a considerable total range of variation — from 3,124,000 pounds in 1920 to 5,292,000 pounds in 1944 — and a slight upward trend, no attempt has been made to divide the 1908-1949 interval into shorter periods. The mean catch of 4,403,000 pounds in 1908-1949 was nearly the same as that for 1885-1892 (4,325,000 pounds) but represents a drop of 1,833,000 pounds from the 1893-1907 average of 6,236,000 pounds. The output of lake trout in all waters of Lake Superior in 1908-1949 was characteristically between 4 and 5 million pounds (in 26 of the 38 years for which there are lake totals). The take exceeded 5 million pounds in 3 years and fell below 4 million pounds in 9 years.

Much of the variation in the production of lake trout in 1908-1949 can be traced to cyclic fluctuations. The tendency toward periodicity was particularly strong during the last 30 years of the period when distinct peaks were reached in 1926-1927, 1935, and 1944 and minimal values occurred in 1920, 1933, and 1940. The last 3 years, 1947-1949, seem to have been part of a period of relatively low yield. The three peaks were spaced about 9 years apart, but the intervals between the minima were unequal (13 and 7 years).

The cyclic fluctuations of the production during the more recent years were distinctly more pronounced for the entire lake than for either of the two major fishing areas, Michigan and Ontario (Fig. 1). This situation was brought about by the similarity of the fluctuations in the two smaller regions — a similarity that tended to accentuate the periodicity when the Michigan and Ontario figures were combined in the computation of totals for the entire lake (these two areas accounted for 80.1 percent of the Lake Superior total in 1930-1949). To some extent the similarities in the production of lake trout in Michigan and Ontario are obscured by differences in the trends in the two areas (noticeably upward in Michigan and slightly downward in Ontario). When these trends were eliminated (through the fitting of straight lines to the data) the coefficient of correlation between the catch in Michigan and Ontario over the 30-year interval, 1920-1949, had the significant ($p < 0.05$) value of 0.456. This figure provides evidence that Michigan and Ontario fishermen may exploit common stocks or stocks subject to similar fluctuations.

PRODUCTION OF LAKE TROUT IN THE DISTRICTS OF THE MICHIGAN WATERS OF LAKE SUPERIOR IN 1885, 1891-1908, AND 1929-1949

Data published by Smith and Snell (1891) made possible the following compilation of the 1885 production of lake trout in five of the six statistical districts into which the State of Michigan waters of Lake Superior have been divided (see Fig. 2 for boundaries of the districts):

District	*Production (thousands of pounds)*
S-2	36
S-3	500
S-4	298
S-5	21
S-6	472
Total	1,327

In the Smith and Snell tabulation the Isle Royal fishery (S-1) was combined with that along the Minnesota "North Shore" (excluding Duluth). It can be stated only that the 1885 catch in district S-1 was not large since the production of lake trout in the Isle Royal and North Shore waters combined amounted to only 56,000 pounds. The 1885 total of 1,327,000 pounds which has long been accepted for the State of Michigan waters is accordingly not greatly in error.

In an earlier paper (Hile, 1949) on the lake trout fishery of Lake Huron the records of production in the statistical districts of the United States waters in 1891-1908 were held to " . . . supply a better idea of the relative natural productive capacities of the different areas than is to be had from the recent figures . . . " The same view cannot be maintained toward the corresponding statistics for Lake Superior (Table 3) because of the strong probability that in some areas the extent of fishing operations and hence the production may have been controlled largely by transportation facilities and other factors not related to the productivity of the waters. In district S-1, for example, the output of lake trout was negligible or nil in 1892-1893, 1896, and 1902-1903. It is not to be inferred, however, that lake trout were not available for the catching in those years. Isle Royal has never had more than a scattering of year-round inhabitants. Traditionally most or all of the fishing in the region has been conducted by operators (mostly from Minnesota) who move to the island during the fishing season; the catch customarily is marketed by way of Duluth. It is readily understandable that poor success in preceding seasons, difficulties in arranging for the

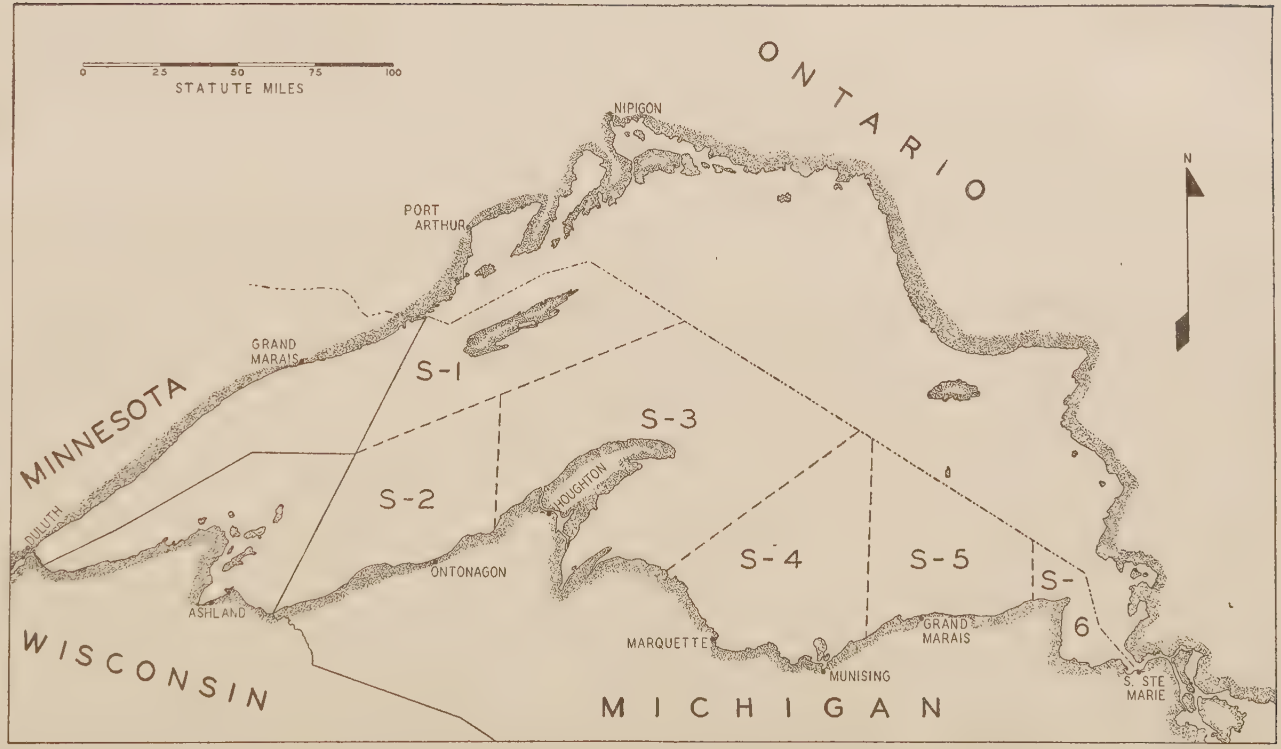

FIGURE 2.—Chart of Lake Superior, showing boundaries of the statistical districts, S-1 to S-6, in the State of Michigan waters.

TABLE 3.—*Production (thousands of pounds) of lake trout in the State of Michigan waters of Lake Superior, 1891-1908.*

Year	District						Total
	1	2	3	4	5	6	
1891	855	99	406	267	40	1,062	2,729
1892	....	82	480	414	422	600	1,998
1893	5	64	396	361	511	1,285	2,622
1894	480	71	253	321	615	766	2,506
1895	477	84	315	338	1	1,011	2,226
1896	....	178	388	539	77	1,276	2,459
1897	460	122	393	464	8	1,173	2,620
1898	387	106	369	572	334	906	2,675
1899	355	132	440	682	351	709	2,668
1900	385	131	448	738	262	610	2,575
1901	412	114	457	776	244	1,034	3,039
1902	....	234	538	1,041	295	370	2,478
1903	....	236	770	1,073	748	1,228	4,055
1904	378	179	511	1,106	1,074	1,082	4,330
1905	317	195	513	913	1,010	1,153	4,101
1906	420	225	307	885	807	973	3,617
1907	558	180	284	674	592	628	2,916
1908	300	112	333	630	309	622	2,306
Average......	[1]322	141	422	655	[2]428	916	2,884
Percentage...	11.2	4.9	14.6	22.7	14.8	31.8	....

[1] 13-year average, 445,000 (1892-1893, 1896, and 1902-1903 excluded).
[2] 14-year average, 541,000 (1891 and 1895-1897 excluded).

transportation of the catch to Duluth, or the existence of good fishing nearer home might have led some or even all of these itinerant operators to forego their customary transfer to Isle Royal in some years. The situation may have been similar in district S-5 where production was unimportant in 1891 and 1895-1897. Even today the principal port, Grand Marais, is without railway service. In the earlier years, long before the development of the motor truck, transportation facilities well may have had a major influence on fishing. Even in the remaining districts in which the catch of lake trout did not fall to such low levels, difficulties of marketing may have affected production.

The 1891-1908 statistics for the districts are nevertheless useful in providing minimal estimates of the quantities of lake trout the several regions were capable of producing over a considerable period of years. We know, for example, that S-6, despite its small area yielded lake trout at an average rate of 916,000 pounds and that the take dropped below 600,000 pounds only once (in 1902) and exceeded a million pounds 9 times in 18 years. Similarly, we know that S-4 produced more than a half million pounds (more than a million in 1902-1904) in each of 11 consecutive years and had an average of 655,000 pounds for the 18-year period. In these two and in the remaining four districts as well, the stocks of lake trout might have been able to support a higher production than that recorded in Table 3. Consequently neither the figures on catch nor the data on percentage contribution to the total for the lake[1] can be accepted as measures of the productive capacities actual or relative, of the different districts. Even these minimal figures on take, however, can be instructive in comparisons with data on the modern yield.

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[1] The term "lake" as employed in this and following sections refers to State of Michigan waters only.

A detailed description of the 1891-1908 fluctuations in the output of lake trout in the several districts would be to little point since we lack information on the variations in the abundance of the species and in the intensity of the fishery. Attention is called only to the similarity of the trends in certain areas. Especially striking is the fact that in four districts (S-2, S-3, S-4, S-5) at least two of the three years of highest output fell within the 4-year period, 1903-1906. The high production in those waters together with much better than average catches in S-6 led to lake totals in 1903-1906 that were all higher than those in any of the other 14 years.

To facilitate comparison between the production statistics for 1891-1908 (Table 3) and 1929-1943, the base period for our modern statistics (Table 4), a summary (Table 5) has been prepared. The differences between the two periods were relatively small in some districts, but others experienced large changes in actual production, in percentage contribution to the total, and in rank among the several regions.

TABLE 4.—*Production (thousands of pounds) of lake trout in the State of Michigan waters of Lake Superior, 1929-1949.*

Year	District						Total	Percentage
	1	2	3	4	5	6		
1929	440	130	431	354	452	117	1,924	93
1930	366	150	417	380	334	73	1,720	83
1931	309	116	541	406	418	170	1,961	95
1932	314	92	457	345	586	177	1,971	96
1933	336	113	442	304	308	202	1,706	83
1934	354	129	555	449	625	381	2,493	121
1935	441	160	564	536	655	240	2,596	126
1936	377	178	539	391	571	263	2,319	113
1937	337	176	517	396	608	258	2,291	111
1938	393	155	538	408	532	158	2,184	106
1939	369	135	460	385	496	88	1,934	94
1940	344	172	450	315	465	96	1,843	89
1941	301	135	467	349	461	157	1,871	91
1942	310	101	568	391	518	134	2,023	98
1943	313	133	647	367	483	147	2,089	101
Average..	354	138	506	385	501	177	2,062	....
Percentage	17.2	6.7	24.5	18.7	24.3	8.6	....	....
1944	417	184	808	477	601	212	2,700	131
1945	384	216	789	520	450	203	2,562	124
1946	374	192	776	553	441	259	2,594	126
1947	337	171	781	418	361	159	2,226	108
1948	386	185	663	402	373	153	2,161	105
1949	334	170	728	432	387	131	2,181	106

In three districts (S-1, S-3, S-5) the production of lake trout was higher in 1929-1943 than in 1891-1908 (increases of 32,000 to 84,000 pounds). The take declined in the remaining three areas. The decrease was small in S-2 (only 3,000 pounds), large in S-4 (270,000 pounds),

TABLE 5.—*Average production (thousands of pounds), percentage of total for State of Michigan waters of Lake Superior, and rank with respect to productivity for the six statistical districts in 1891-1908 and 1929-1943.*

District	1891—1908			1929—1943			Change from 1891—1908 to 1929—1943		
	Average production	Percentage of total	Rank	Average production	Percentage of total	Rank	Average production	Percentage of total	Rank
1	322	11.2	5	354	17.2	4	32	6.0	1
2	141	4.9	6	138	6.7	6	— 3	1.8	0
3	422	14.6	4	506	24.5	1	84	9.9	3
4	655	22.7	2	385	18.7	3	—270	—4.0	—1
5	428	14.8	3	501	24.3	2	73	9.5	1
6	916	31.8	1	177	8.6	5	—739	—23.2	—4
Total	2,884	....	....	2,062	....	....	—822	....	....

and tremendous in S-6 (739,000 pounds). This drop in S-6, where the 1929-1943 average of 177,000 pounds amounted to only 19.3 percent of the 1891-1908 mean of 916,000 pounds accounted for much of the decrease of 822,000 pounds in the combined districts. The decreases in S-4 and S-6 provide almost conclusive evidence of lowered productivity of the fishery in the two areas.

The differences among the districts in the extent and direction of the change in production were accompanied by some pronounced shifts in the ranking with respect to the contribution to the total output. The greatest change occurred in S-6 which ranked first and contributed 31.8 percent of the 1891-1908 yield but had fallen to fifth position and accounted for only 8.6 percent of the take in 1929-1943. District S-4 also suffered a decrease in the percentage contributed to the total (from 22.7 to 18.7 percent) and a drop in ranking (from second to third). All of the remaining districts experienced increases in the percentage of the total (from 1.8 in S-2 to 9.9 in S-3) and all but S-2 improved their rankings. District S-3 moved from fourth position in 1891-1908 to first in 1929-1943, S-5 from third to second, and S-1 from fifth to fourth. District S-2 ranked sixth in both periods. These changes in percentage contribution resulted in a shift toward the west in the centers of production. Districts S-1, S-2, and S-3 which together contributed only 30.7 percent of the 1891-1908 catch accounted for 48.4 percent of the take in 1929-1943. The percentage for S-4, S-5, and S-6 dropped correspondingly from 69.3 in the former period to 51.6 in the latter.

Despite certain irregularities in the 1929-1949 data and some difference among the districts in actual timing, all areas exhibited the periodic fluctuations mentioned in the comments of the preceding section on production in the State of Michigan waters and in Lake Superior as a whole. These fluctuations were characterized by peaks in the middle 1930's and middle 1940's (Table 6; see also Table 4 and Figs. 3 and 4).

The earlier peak fell in 1935 in four districts, in 1934 in one, and in 1936 in one. The years of the second peak were 1944 in three districts, 1945 in one and 1946 in two. The intervening minimum year was 1939 in one district, 1940 in two, 1941 in two and 1942 in one. The interval between the peaks was 9 years for districts S-1, S-2, S-3, and S-5, 11 years for S-4, and 12 years for S-6.

As would be expected, the production statistics for the combined districts exhibited a similar cyclic trend (Table 6 and right-hand columns of Table 4). From a level of 1,924,000 pounds (93 percent of the 1929-1943 mean) in 1929 the take dropped to 1,720,000 pounds (83 percent) in 1930, increased to 1,971,000 (96 percent) pounds in 1932, declined to 1,706,000 pounds (83 percent) in 1933 and then rose to a peak of 2,596,000 pounds (126 percent) in 1935. Following this maximum the take decreased consistently to a low of 1,843,000 pounds (89 percent) in 1940 and then rose consistently to 2,700,000 pounds (131 percent) in 1944. This second peak was followed by a new, though irregular

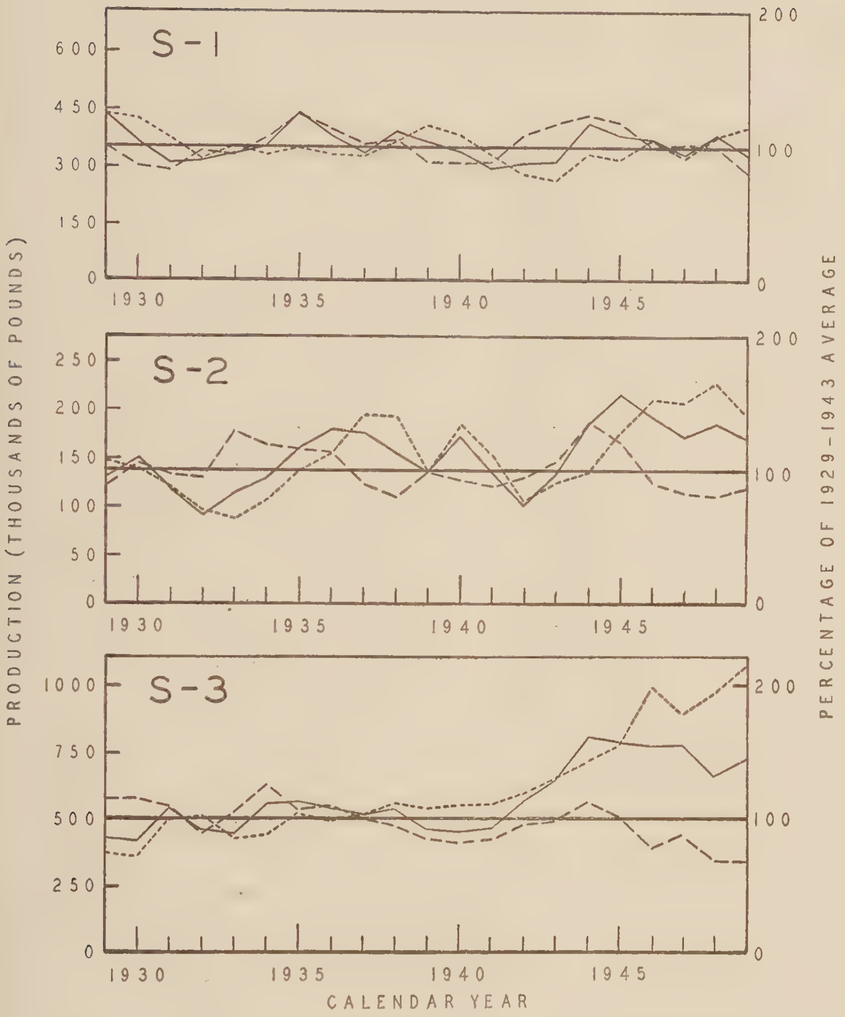

FIGURE 3.—Production (solid line) and index of abundance (long dashes) of lake trout and fishing intensity for the species (short dashes) in districts S-1, S-2, and S-3, 1929-1949, expressed as percentages (scale at right) of the 1929-1943 mean. Production given also in pounds (scale at left).

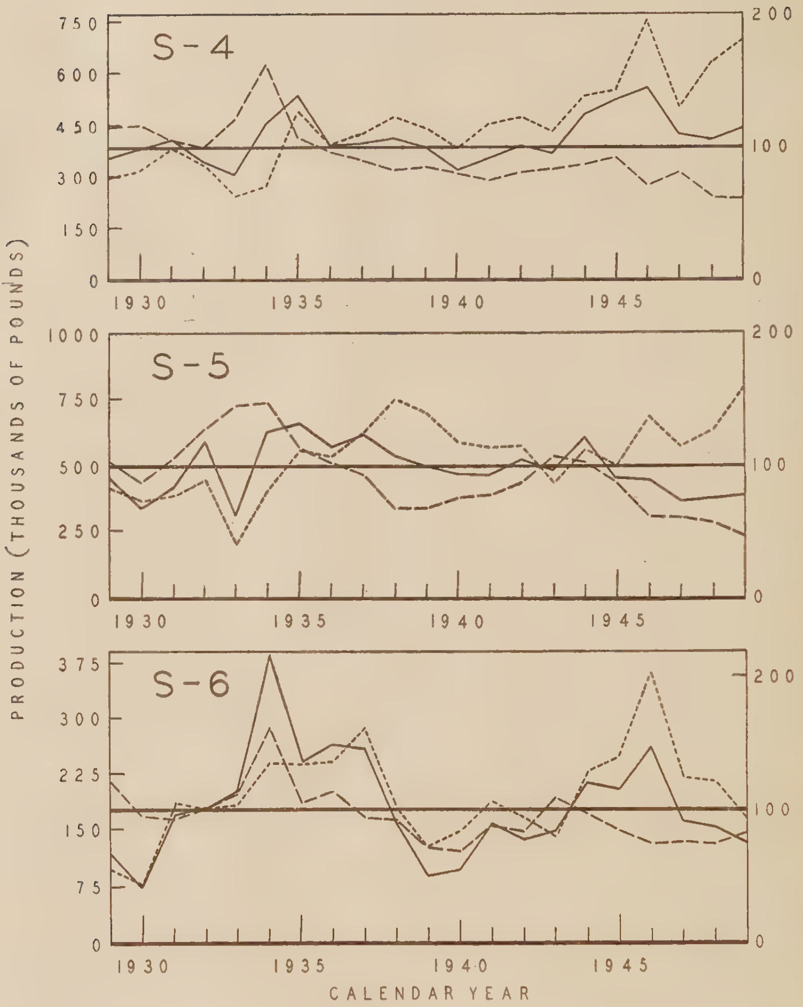

FIGURE 4.—Production (solid line) and index of abundance (long dashes) of lake trout and fishing intensity for the species (short dashes) in districts S-4, S-5, and S-6, 1929-1949, expressed as percentages (scale at right) of the 1929-1943 mean. Production given also in pounds (scale at left).

TABLE 6.—*Peak years and years of the intervening minimum in the cyclic fluctuations of production of lake trout in the State of Michigan waters of Lake Superior, 1929-1949.*

District	First peak			Intervening minimum			Second peak			Interval between peaks (years)
	Year	Production		Year	Production		Year	Production		
		Thousands of pounds	Percentage of average		Thousands of pounds	Percentage of average		Thousands of pounds	Percentage of average	
1..........	1935	441	125	1941	301	85	1944	417	118	9
2..........	1936	178	129	1942	101	73	1945	216	157	9
3..........	1935	564	111	1940	450	89	1944	808	160	9
4..........	1935	536	139	1940	315	82	1946	553	144	11
5..........	1935	655	131	1941	461	92	1944	601	120	9
6..........	1934	381	215	1939	88	50	1946	259	146	12
All.......	1935	2,596	126	1940	1,843	89	1944	2,700	131	9

decline to 2,161,000 pounds (105 percent) in 1948. The slight increase in 1949 (to 2,181,000 pounds or 106 percent) may mark the beginning of a new upswing or may represent merely an irregularity in the downward trend.

ABUNDANCE OF LAKE TROUT IN THE DISTRICTS OF THE MICHIGAN WATERS OF LAKE SUPERIOR, 1929-1949

The estimates of the fluctuations in the abundance or availability of lake trout in the several districts (Table 7; see also Figs. 3 and 4) have been based largely on the records of the catch per unit of effort of large-mesh (4½ inches and greater, extension measure) gill nets (Table 8). During the base period 1929-1943 that gear accounted for 64.5 percent of the total catch of the combined districts.[2] Set-hooks (Table 9) which contributed 30.5 percent of the 1929-1943 take were of less significance but still important. Pound nets (Table 10) produced but 2.1 percent of the 15-year catch and were sufficiently important to be considered in the estimation of abundance in S-3 and S-6 only.

The abundance percentages of Table 7 exhibit a cyclic fluctuation (Table 11) closely similar to that described in the previous section on production. (The only difference of any consequence is the tendency

TABLE 7.—*Abundance of lake trout in the State of Michigan waters of Lake Superior according to statistical district and for the districts combined, 1929-1949.*

[Expressed as percentages of the 1929-1943 mean]

Year	District						Average[1]
	1	2	3	4	5	6	
1929	100	87	114	115	103	120	108
1930	85	105	114	117	87	95	101
1931	82	96	108	105	105	93	100
1932	96	94	88	100	127	100	103
1933	94	128	103	121	145	112	117
1934	106	118	125	162	147	161	137
1935	124	115	106	107	113	104	111
1936	113	113	109	96	102	113	106
1937	102	89	99	90	93	93	95
1938	106	79	94	83	67	92	86
1939	89	98	84	85	67	71	81
1940	88	92	81	80	75	68	80
1941	89	87	83	75	77	87	82
1942	109	94	94	81	86	83	91
1943	117	105	98	83	106	108	102
1944	123	135	111	87	102	96	107
1945	118	120	100	92	86	84	98
1946	100	90	77	71	61	74	77
1947	102	82	86	81	60	75	80
1948	100	80	67	62	56	74	70
1949	81	86	66	60	46	82	65

[1] In the computation of the average the abundance percentage of each district was weight by the percentage of the total 1929-1943 production contributed by that district.

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[2] Statements as to the percentage of the total catch produced by different gears are based on original records not presented here.

TABLE 8.—*Catch (pounds) of lake trout per lift of 10,000 linear feet of large-mesh gill nets (4½ inches and greater, extension measure) in the several districts of the State of Michigan waters of Lake Superior, 1929-1949.*

Year	Catch per lift of 10,000 feet of large-mesh gill nets					
	S-1	S-2	S-3	S-4	S-5	S-6
1929	219	149	201	242	366	208
1930	203	158	197	259	305	231
1931	178	137	188	232	362	225
1932	231	143	149	211	444	243
1933	215	206	169	227	519	326
1934	245	185	196	308	519	353
1935	271	153	162	215	388	289
1936	263	177	178	220	313	257
1937	220	144	143	172	297	219
1938	223	132	123	156	203	228
1939	196	170	117	163	206	143
1940	206	157	115	168	243	190
1941	219	140	125	159	260	209
1942	248	154	150	168	290	217
1943	274	170	150	171	360	255
Average	227	158	158	205	338	240
1944	270	222	166	162	351	218
1945	261	200	154	176	286	208
1946	207	144	112	139	197	217
1947	226	134	129	160	199	221
1948	235	126	101	117	188	183
1949	185	138	102	116	160	198

TABLE 9.—*Catch (pounds) of lake trout per lift of 1,000 set-hooks in the several districts of the State of Michigan waters of Lake Superior, 1929-1949.*

Year	Catch per lift of 1,000 set-hooks					
	S-1	S-2	S-3	S-4	S-5	S-6
1929	687	195	166	285	271	358
1930	480	273	162	251	256	317
1931	559	268	148	222	330	317
1932	557	235	152	239	376	300
1933	593	303	199	370	313	384
1934	648	288	262	448	407	451
1935	874	314	221	272	331	293
1936	672	266	194	217	354	335
1937	709	205	200	246	310	269
1938	771	185	208	230	286	241
1939	587	193	169	238	351	210
1940	530	179	179	191	275	175
1941	490	185	192	178	269	180
1942	697	181	221	196	294	257
1943	652	225	258	210	364	374
Average	634	233	195	253	319	297
1944	938	235	322	293	324	295
1945	810	236	295	310	283	210
1946	848	196	239	213	251	128
1947	704	172	229	234	209	147
1948	581	184	199	215	200	106
1949	517	190	171	195	149	112

TABLE 10.—*Catch (pounds) of lake trout per lift of one pound net in districts S-3 and S-6 of the State of Michigan waters of Lake Superior, 1929-1949.*

Year	Catch per lift of one pound net		Year	Catch per lift of one pound net	
	S-3	S-6		S-3	S-6
1929	60	35	1941	63	14
1930	72	6	1942	50	7
1931	70	18	1943	86	13
1932	38	17			
1933	31	14	Average	56	18
1934	42	37			
1935	47	21	1944	37	18
1936	49	26	1945	45	15
1937	62	20	1946	80	15
1938	54	18	1947	95	3
1939	79	16	1948	32	8
1940	44	7	1949	54	4

for the peaks and the intervening minimum of production to fall a little later than those of abundance and for the first of the two peaks to be the higher in the abundance curves.) The first of the two peaks of abundance occurred in 1934 in four districts, in 1933 in one, and in 1935 in one. The year of the intervening minimum was 1940 in three areas, 1938 in two (the 1938 and 1939 figures were identical in S-5), and 1941 in one. The second peak was reached in 1944 in three districts, in 1943 in two, and in 1945 in one. With the single exception of S-2, the level of abundance attained at the second peak was lower than that of the first. Especially striking was the situation in S-4 where the abundance percentage attained the high figure of 162 in 1934 but failed even to reach the 1924-1943 mean of 100 at the second peak in 1945. The difference between the first and second peaks was large also in S-5 and S-6, was reduced in S-3, and unimportant in S-1. In the four eastern districts the differences between the earlier and later peaks seem to be part of a general downward trend in the level of abundance.

The cyclic character of the fluctuations in availability and the general downward trend are distinctly apparent in the data for the combined

TABLE 11.—*Peak years and years of the intervening minimum in the cyclic fluctuations of abundance of lake trout in the State of Michigan waters of Lake Superior, 1929-1949.*

District	First peak		Intervening minimum		Second peak		Interval between peaks (years)
	Year	Abundance	Year	Abundance	Year	Abundance	
1	1935	124	1940	88	1944	123	9
2	1933	128	1938	79	1944	135	11
3	1934	125	1940	81	1944	111	10
4	1934	162	1941	75	1945	92	11
5	1934	147	1938-39	67	1943	106	9
6	1934	161	1940	68	1943	108	9
All	1934	137	1940	80	1944	107	10

districts (right of Table 7). From a level of 108 in 1929 the abundance percentage declined to 100 in 1931, increased to a maximum of 137 in 1934, decreased to a minimum of 80 in 1940, rose to a new peak of 107 in 1944, and started again on a decline (interrupted by a small increase in 1947) that led to a value of only 65 in 1949—the lowest level in the 21-year interval.

That the fluctuations in the availability of lake trout in the different districts exhibited certain similarities is obvious from the previous comments on cyclic fluctuations. To provide a more precise measure of the extent of these agreements coefficients of correlation (r) between abundance percentages over the 21-year period, 1929-1949, were computed for all possible pairings of the districts (Table 12). The coefficients for all 10 combinations of the mainland districts (S-2 through S-6) were significant and those for the four easterly districts (S-3 through S-6) were extremely high ($p < 0.001$ for all six values). Somewhat lower were the correlations between the fluctuations of abundance in these four easterly districts and those in S-2, the other mainland district, but even of these coefficients two (S-2 and S-3; S-2 and S-5) were significant at the 1-percent level of probability and the remaining two (S-2 and S-4; S-2 and S-6) at the 5-percent level. The availability of lake trout in the Isle Royal region (S-1) seems to have varied independently from that in most mainland waters. Only one of the coefficients, that between the percentages for S-1 and S-2 was significant ($p < 0.05$). The remaining coefficients were all positive but only one of them ($r = 0.372$ for S-1 and S-3) reached a figure corresponding to a 10-percent level of probability.

TABLE 12.—*Coefficients of correlation* (r) *between annual fluctuations in the abundance of lake trout in the statistical districts of the State of Michigan waters of Lake Superior, 1929-1949.*

[Values of r corresponding to probabilities (p) of 0.10, 0.05, 0.01 and 0.001 are 0.369, 0.433, 0.549, and 0.665, respectively]

District	District					
	S-1	S-2	S-3	S-4	S-5	S-6
S-1	....	0.484	0.372	0.094	0.275	0.286
S-2	0.484	....	0.625	0.526	0.663	0.475
S-3	0.372	0.625	....	0.845	0.749	0.769
S-4	0.094	0.526	0.845	....	0.831	0.850
S-5	0.275	0.663	0.749	0.831	....	0.811
S-6	0.286	0.475	0.769	0.850	0.811	....

We are not in position to speculate as to whether the fishermen in the areas exhibiting significantly correlated fluctuations in the abundance of lake trout are drawing on a common stock or whether they are merely exploiting populations in which the factors controlling availability in 1929-1949 were the same or subject to similar annual fluctuations. We need first to obtain definite information on the nature of the factors that control the abundance of lake trout and on the extent of the migrations undertaken by that fish.[3]

INTENSITY OF THE FISHERY FOR LAKE TROUT IN THE DISTRICTS OF THE MICHIGAN WATERS OF LAKE SUPERIOR, 1929-1949

The distinctly cyclic fluctuations that were described in the preceding sections on the production and abundance of lake trout are much less apparent in the data on fishing intensity (Table 13; Figs. 3 and 4). Although a suggestion of periodicity is to be seen in the figures on fishing intensity in several of the districts, the fluctuations could be termed sharply cyclic only in S-6 (distinct peaks in 1937 and 1946 with a minimum in 1939). If the decline in 1949 is interpreted as the beginning of a downward trend from a peak in 1948, the fluctuations in S-2 also can be termed periodic (earlier peak in 1937; minimum in 1942). In some districts (S-3, S-4, S-5) the data suggest the possibility that a tendency toward a cyclic fluctuation may have been obscured by a long-term upward trend that was becoming stronger toward the close of the 21-year period.

TABLE 13.—*Intensity of the fishery for lake trout in the State of Michigan waters of Lake Superior, 1929-1949.*

[The unit corresponds to 1/1500 of the total expected catch for all districts over the 15-year period, 1929-1943]

Year	District						Total
	1	2	3	4	5	6	
1929	20.9	7.1	17.9	14.6	20.9	4.5	85.9
1930	20.4	6.7	17.3	15.4	18.2	3.6	81.6
1931	17.9	5.7	23.8	18.5	19.0	8.5	93.4
1932	15.4	4.6	24.6	16.3	21.9	8.2	91.0
1933	16.9	4.2	20.5	11.9	10.1	8.4	72.0
1934	15.8	5.1	21.2	13.2	20.2	10.9	86.4
1935	16.8	6.6	25.1	23.9	27.6	10.9	110.9
1936	15.9	7.5	23.6	19.2	26.7	11.0	103.9
1937	15.7	9.3	24.8	20.8	31.1	13.1	114.8
1938	17.6	9.2	27.1	23.4	37.4	8.2	122.9
1939	19.7	6.5	25.9	21.6	34.9	5.9	114.5
1940	18.6	8.8	26.4	18.7	29.3	6.8	108.6
1941	15.9	7.4	26.7	22.0	28.2	8.6	108.8
1942	13.5	5.1	28.5	23.0	28.6	7.7	106.4
1943	12.7	6.0	31.4	20.9	21.5	6.4	98.9
Average......	16.9	6.7	24.3	18.9	25.0	8.2	....
1944	16.1	6.5	34.5	26.1	27.9	10.4	121.5
1945	15.4	8.5	37.4	26.8	24.8	11.4	124.3
1946	17.7	10.1	47.9	37.0	34.2	16.5	163.4
1947	15.6	9.9	43.1	24.4	28.5	10.1	131.6
1948	18.3	10.9	47.0	30.8	30.8	9.9	147.7
1949	19.4	9.4	52.2	34.0	39.7	7.5	162.2

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[3] The continuation and expansion of tagging experiments started on a limited scale in October 1950 should yield data on this point. The first 6 recoveries (all made in November and December 1950 and January 1951) from 116 lake trout tagged at Bete Grise Bay on the east shore of the Keweenaw Peninsula near the tip suggest that adult lake trout may undertake extensive migrations. Only two of the six fish were recaptured locally (that is, within a range of 20-30 miles). Two were taken off Munising, Michigan, one off the Gooseberry River in Minnesota waters and one near the Slate Islands in extreme northern Lake Superior (Ontario waters).

TABLE 14.—*Two years of highest and of lowest fishing intensity and comparison of average intensity in 1944-1949 and 1946-1949 with the mean for the base period 1929-1943 in the statistical districts of the State of Michigan waters of Lake Superior.*

District	Years of lowest ntensity	Years of highest intensity	Average intensity in period					
			1929—1943		1944—1949		1946—1949	
			Units[1]	Percentage[2]	Units[1]	Percentage[2]	Units[1]	Percentage[2]
1	1943—1942	1929—1930	16.9	100	17.1	101	17.8	105
2	1933—1932	1948—1946	6.7	100	9.2	137	10.1	151
3	1930—1929	1949—1946	24.3	100	43.7	180	47.6	196
4	1933—1934	1946—1949	18.9	100	29.8	158	31.6	167
5	1933—1930	1949—1938	25.0	100	31.0	124	33.3	133
6	1930—1929	1946—1937	8.2	100	11.0	134	11.0	134
All	1933—1930	1946—1949	100.0	....	141.8	....	151.2	....

[1] See caption of Table 13 for definition of unit.
[2] Percentage of 1929—1943 mean for district.

This upward trend in the fishing pressure is without question the most significant feature of the data of Table 13 and Figures 3 and 4. Because the trends in some districts are clouded by random and cyclic fluctuations certain of the data of Table 13 have been summarized in Table 14.

The agreement among the five mainland districts (S-2 to S-6) with respect to years of highest and lowest intensity and the level of fishing pressure in recent years was generally good. In the listing of the two years of lowest fishing intensity, for example, all 10 entries fell within the 6-year period, 1929-1934. Similarly, 8 of the 10 years of highest intensity came within the 4-year interval, 1946-1949 (see left-hand part of Table 14). The districts agreed also in showing a general level of fishing well above the 1929-1943 mean during recent years (see right-hand part of Table 14). Over the 6 years, 1944-1949, the average intensity expressed as a percentage of the 15-year mean ranged from 124 percent in S-5 to 180 percent in S-3. With the exception of S-6 these percentages were even higher in the 4 most recent years for which we have data—from 133 percent in S-5 to 196 percent in S-3.

District S-1 did not share this high level of fishing intensity that characterized the mainland areas. The years of minimum fishing pressure were fairly recent (1943 and 1942) whereas the most intensive fishing occurred in 1929 and 1930. Furthermore, the level of intensity was but little above the 1929-1943 mean in 1944-1949 (101 percent of average) and 1946-1949 (105 percent).

Despite certain erratic and possibly some periodic fluctuations, the fishing intensity for lake trout in the combined districts (right of Table 13) shows distinctly the long-term upward trend described for the mainland waters. Fishing intensity was consistently below the 1929-1943 average during the 6 years 1929-1934. The value of 72.0 in 1933 was the lowest in the 21 years for which we have records. From the 1933 minimum, fishing pressure increased irregularly to a peak of 122.9 in 1938 and then declined to 98.9 in 1943 (the only year since 1934 in which intensity has been below average). The intensity index rose sharply to 121.5 in 1944, increased a little in 1945, and then jumped to the 21-year maximum of 163.4 in 1946. A drop to 131.6 in 1947 was followed by two successive increases that carried the index to 162.2 —only a little short of the 1946 figure—in 1949. The average figure for 1944-1949 (Table 14) was 141.8 and the mean for the 4 most recent years, 1946-1949, was 151.2. In every year after 1944 the fishing intensity exceeded (usually by a wide margin) the maximum recorded for 1929-1944.

RELATIONSHIPS AMONG PRODUCTION, ABUNDANCE, AND FISHING INTENSITY

The relationships among the production and abundance of lake trout and the intensity of the lake trout fishery in the combined districts of the State of Michigan waters of Lake Superior (Table 15; Fig. 5) are in disagreement with situations usually encountered and commonly held to be typical under normal fishing conditions. In this "normal" situation the fluctuations are such that production serves as a reasonably dependable indicator of changes in abundance, and fishing intensity tends to increase with rising abundance and to decrease with declining abundance.

TABLE 15.—*Fluctuations in the production and abundance of lake trout and in the intensity of the lake trout fishery in the State of Michigan waters of Lake Superior.*

[Expressed as percentages of the 1929-1943 mean]

Year	Production	Abundance	Intensity
1929	93	108	86
1930	83	101	82
1931	95	100	93
1932	96	103	91
1933	83	117	72
1934	121	137	86
1935	126	111	111
1936	113	106	104
1937	111	95	115
1938	106	86	123
1939	94	81	114
1940	89	80	109
1941	91	82	109
1942	98	91	106
1943	101	102	99
1944	131	107	122
1945	124	98	124
1946	126	77	163
1947	108	80	132
1948	105	70	148
1949	106	65	162

Van Oosten, Hile, and Jobes (1946) held that " . . . there is good reason to believe that under normal conditions (without disruption in the methods or regulations of the fishery), over limited areas, and for short periods of years, large increases or decreases of production may serve as reliable indicators of increases or decreases in the abundance of fish on the grounds." Earlier, Doan (1942) had expressed similar views and had considered it valid to estimate fluctuations in the abund-

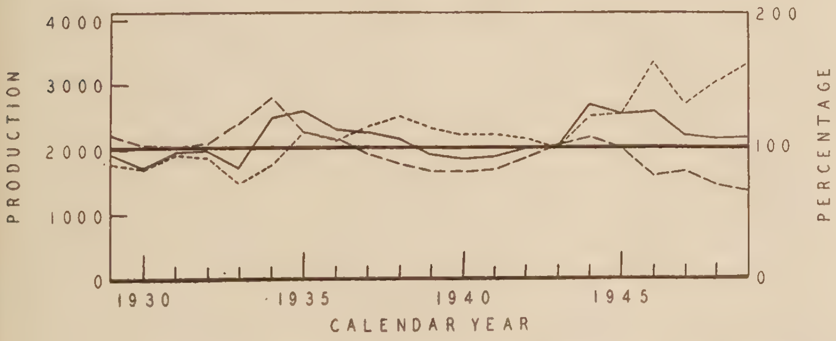

FIGURE 5.—Production (solid line) and index of abundance (long dashes) of lake trout and fishing intensity for the species (short dashes) in the combined districts of the State of Michigan waters of Lake Superior, 1929-1949, expressed as percentages of the 1929-1943 mean (scale at right). Production in thousands of pounds shown by scale at left.

ance of Lake Erie fish from production statistics. In support of his procedure he cited the close agreement between the fluctuations in the catch per net and the total production of walleyes *(Stizostedion v. vitreum)* in four areas of Lakes Huron and Michigan (data from Hile, 1937) and in Lake Erie. More recently, Hile (1949) demonstrated a significant positive correlation between the abundance and production of lake trout in four of six statistical districts and for the combined districts in the United States waters of Lake Huron and Hile, Eschmeyer, and Lunger (1951) observed a similar correlation in five of eight districts and for the combined areas in the State of Michigan waters of Lake Michigan.

In the Michigan waters of Lake Superior the correlation between the production and abundance of lake trout in 1929-1949 was "significant" in S-1 ($r = 0.491$) and "highly significant" in S-6 ($r = 0.608$).[4] The values of the coefficient for the remaining districts and for all areas combined were: S-2, 0.042; S-3, —0.259; S-4, —0.060; S-5, 0.370; all six districts, 0.143. On the whole, therefore, production was highly unreliable as an indicator of changes in the abundance of lake trout in Lake Superior.

The observed usefulness of production statistics as indicators (but not necessarily as measures) of changes of abundance in so many situations hinges on a general tendency for fishing intensity and the abundance of fish to vary independently or to be correlated positively. A description of the relationship between fishing intensity and abundance held by Van Oosten, Hile, and Jobes (1946) to represent normal conditions was given in their comments on the statistics of the whitefish fishery of the State of Michigan waters of Lake Michigan.

> . . . fishing intensity and yield were above average in a large majority of the years in which the abundance of whitefish was above average, and, conversely, fishing intensity and production were below average in the majority of the years in which the abundance of whitefish was below average. There was a tendency also for the percentages of fishing intensity and catch to be greater than the abundance percentages when abundance was above average and less than the abundance percentages when abundance was below average. The curves of fishing intensity tended to lie outside (with reference to the average) the curves of abundance, and the curves of production tended to fall outside both the curves of abundance and fishing intensity.

The coefficient of correlation between the indices of abundance of whitefish and the intensity of the fishing for that species in the State of Michigan waters of Lake Michigan in 1929-1939 was 0.70.

With the Lake Superior lake trout, contrary to the usual relationship just described, the abundance of lake trout and fishing intensity were correlated negatively as the following coefficients of correlation prove.

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[4] With 19 degrees of freedom the absolute values of r corresponding to the 5- and 1-percent levels of probability are 0.433 and 0.549 respectively.

District	r
S-1	—0.590
S-2	—0.568
S-3	—0.728
S-4	—0.768
S-5	—0.804
S-6	—0.025
Combined districts	—0.760

Of the coefficients listed above only the one for S-6 was too small to be considered significant; the values for S-1 and S-2 were beyond the 1-percent level of probability ($r = \pm 0.549$ at $p = 0.01$) and those for S-3, S-4, and S-5 and for the combined districts were beyond the 0.1-percent value ($r = \pm 0.665$ at $p = 0.001$). Especially striking in the data on abundance and fishing intensity is the disagreement in the long-term trends. Despite certain irregularities and a strong indication of periodicity, the trend of abundance of lake trout in 1929-1949 was distinctly downward, and during the same period the trend of fishing pressure was just as definitely upward. This difference of trends led to a strong divergence of the curves of abundance and fishing intensity in the years following 1943.

The sharp rise in the intensity of the fishery for lake trout during recent years in the face of the rapidly declining abundance of the species was made possible first by exceptionally favorable market conditions and second by the existence in Lake Superior of a base-period (1929-1943) average return per unit of effort so high that profitable operations still could be carried on at a *relativcly* low level of abundance.

TABLE 16.—*Production of lake trout (thousands of pounds) in Lake Michigan and in the United States waters of Lakes Huron and Superior and percentage distribution of the combined catch among the three lakes 1935-1949.*

Year	Lake Huron		Lake Michigan		Lake Superior		Total production
	Production	Percentage	Production	Percentage	Production	Percentage	
1935	1,743	17.3	4,873	48.3	3,476	34.4	10,092
1936	1,400	14.9	4,763	50.7	3,233	34.4	9,396
1937	1,340	14.2	4,988	53.0	3,085	32.8	9,413
1938	1,270	13.6	4,906	52.5	3,167	33.9	9.343
1939	1,372	14.0	5,660	57.9	2,744	28.1	9,776
1940	940	9.5	6,266	63.4	2,677	27.1	9,882
1941	892	8.5	6,788	64.4	2,854	27.1	10,534
1942	728	7.2	6,484	63.7	2,959	29.1	10,171
1943	459	4.4	6,860	66.2	3,053	29.4	10,372
1944	363	3.4	6,498	61.3	3,740	35.3	10,600
1945	173	1.9	5,437	60.6	3,369	37.5	8,979
1946	38	0.5	3,974	53.3	3,444	46.2	7,456
1947	12	0.2	2,425	44.9	2,964	54.9	5,402
1948	4	0.1	1,197	28.8	2,954	71.1	4,155
1949	1	0.0	342	10.4	2,966	89.6	3,309

The collapse of the lake trout fishery first in Lake Huron and later in Lake Michigan gave Lake Superior fishermen an increasing share in and finally almost a monopoly on the domestic production (Table 16). In 1935, the last year in which the Lake Huron catch exceeded the modern average (Hile, 1949), the percentage distribution of the combined take in the upper lakes[5] was: Lake Huron, 17.3; Lake Michigan, 48.3; Lake Superior, 34.4. In the 9-year period 1935-1943 the percentage of the three-lake total produced in Lake Superior fell within the narrow range 27.1-34.4. An upward trend in the percentage for Lake Superior started in 1942, carried past the 50-percent level in 1947 and reached the high figure of 89.6 percent in 1949. The increase in the relative contribution of Lake Superior was accompanied by a downward trend in the combined catch of lake trout in the upper lakes. During the years 1935-1944 the output varied between 9,343,000 pounds and 10,600,000 pounds, but in 1945 it started a rapid decline that had reached 3,309,000 pounds in 1949. This decrease in the supply placed the Lake Superior fishermen in a highly advantageous position. Demand was brisk, prices were good, and the danger of glutting the market was insignificant.

Despite the economic advantages enjoyed by Lake Superior fishermen, the question still exists as to how fishing intensity could increase in recent years when abundance was declining so rapidly. Even with the best of market conditions, there are limits of availability below which profitable operations are impossible. In earlier accounts of the collapse of the lake trout fishery in Lake Huron (Hile, 1949) and Lake Michigan (Hile, Eschmeyer, and Lunger, 1951) the 50-percent level of production was taken as the "critical point" in the decline but the 70-percent level was selected for abundance because " . . . the fishery had all but disappeared by the time that level of abundance [50 percent] was reached . . . " (Hile, 1949). In Lake Superior, however, the lake trout fishery was far from disappearing in 1948 and 1949 when the abundance percentages for the combined districts were 70 and 65 percent respectively. On the contrary, fishing pressure was high (148 and 162 percent of average) and production was good (105 and 106 percent) in both years. The explanation of continued high fishing intensity and production in years of low abundance is to be found in the comparison of the 1929-1943 average catch per unit of fishing effort in the several statistical districts of the State of Michigan waters of Lakes Huron, Michigan, and Superior (Table 17). These figures are the absolute standards from which the percentage fluctuations of abundance in the different areas were computed. Although a detailed comparison of the average catch per lift for each Lake Superior district with the average for the corresponding gear in each district of Lake Huron and Lake Michigan will reveal certain exceptions, it can be stated, nevertheless, that the standards were generally the higher in Lake Superior. In other words better fishing (in terms of catch per unit of effort) is required in most Lake Superior districts to give an

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[5] The production of lake trout has been nil in recent years in Lake Erie and has been unimportant in Lake Ontario—consistently below 20,000 pounds and sometimes less than 10,000 pounds.

TABLE 17.—*Average catch of lake trout (pounds) per lift of 10,000 linear feet of large-mesh (4½ inches and greater) gill nets and per lift of 1,000 set-hooks in the statistical districts of the State of Michigan waters of Lakes Huron, Michigan, and Superior, 1929-1943.*

Lake Huron			Lake Michigan			Lake Superior		
District	Gill nets	Set-hooks	District	Gill nets	Set-hooks	District	Gill nets	Set-hooks
H-1	113	207	M-1	102	184	S-1	227	634
H-2	196	215	M-2	151	190	S-2	158	233
H-3	154	189	M-3	131	143	S-3	158	195
H-4	161	109	M-4	105	128	S-4	205	253
H-5	148	184	M-5	101	242	S-5	338	319
H-6	75	191	M-6	109	121	S-6	240	297
			M-7	179	164			
			M-8	160	174			
Average	141	182	Average	130	168	Average	221	322

estimate of normal abundance (100 percent) than is necessary in most areas of Lakes Huron and Michigan. Furthermore, an abundance of only 65 or 70 percent in Lake Superior corresponds to a success of fishing that would be considered normal or better in most of Lake Huron or Lake Michigan.

Comforting as it may be to know that the quality of lake trout fishing in the Michigan waters of Lake Superior was still good in 1948 and 1949 in spite of the relatively low availability of fish, the general situation must be recognized as dangerous. The trends as shown in Table 15 and Figure 5 cannot continue much longer. Still further decreases in the abundance of lake trout inevitably must reduce the catch per unit of effort to the level at which operations are no longer profitable. When that point is reached, fishing intensity and production must be expected to drop abruptly. Only a reversal of the present trend in the abundance of lake trout can save the fishery from disaster.

The appraisal of the status of the stocks of lake trout is made even more discouraging by the knowledge that our estimates of abundance in the past few years have been too high and our estimates of fishing intensity too low. Three factors have contributed to our errors: the gradual replacement of cotton and linen gill nets by the more efficient nylon nets[6]; the extension of operations to deeper water as the result of the development of floats capable of withstanding pressures up to 120 fathoms and deeper; the installation on numerous boats of sonic depth-finders which made possible the more accurate placement of the nets at the desired depth and also the location of new grounds in areas formerly believed to be uniformly too deep for fishing. As a result of these improvements gill-netters in recent years have been taking greater quantities of fish per unit of fishing effort than would have been possible at the same level of abundance with the gear and equipment of much of the 1929-1943 base period. At the same time the actual pressure on the population has been greater than the mere length of gill nets (the principal gear) lifted would indicate.

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[6] We are without good information on the relative efficiency of nylon and cotton or linen gill nets. The advantage of the nylon webbing doubtless varies with the species, the method of hanging the net, and possibly with other factors. The only quantitative data on the efficiency of nylon nets in the lake trout fishery of Lake Superior are from observations by Mr. Leo F. Erkkila, Fishery Research Biologist, in charge of the Service's field station at Marquette, Michigan, on a small number of lifts from that port in which both nylon and linen nets were fished. According to Mr. Erkkila's counts the nylon nets in these gangs took 2½ times as many fish as the linen nets. The effect of the introduction of nylon netting on the data given in this paper is probably small and limited to 1949. According to information supplied by fishermen, nylon netting was not fished before 1949 and its use was limited in that year. At Marquette nylon nets appear to have been fished for the first time in 1950.

We should be in much better position to speculate as to the future of the lake trout fishery in Lake Superior if we knew the cause of the present downward trend of abundance. The upward trend of fishing pressure and the high negative correlation between abundance and fishing intensity in most districts and in the combined areas invite the belief that the two may be related causally — that rising fishing pressure has brought about a decrease of abundance and that the fishermen in the face of this reduced availability have intensified their efforts in order to keep production at a good level. If so, a continuation of present trends until fishing becomes unprofitable is to be anticipated. On the other hand, it is possible that the rising fishing pressure has been merely the result of a natural decline in abundance but has not contributed materially to it. In this event, we can hope for a natural upturn of abundance which would relieve the precarious status of the fishery. Regardless of the causes that led to the present situation, the fact remains that the lake trout stocks of the State of Michigan waters of Lake Superior are fast nearing a dangerously low level and are in poor condition to withstand the impending ravages of a growing population of sea lampreys.

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FOOD OF YOUNG PIKE, *ESOX LUCIUS* L., AND ASSOCIATED FISHES IN PETERSON'S DITCHES, HOUGHTON LAKE, MICHIGAN[1]

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Abstract

Stomach contents of 551 young pike (11-152 millimeters in length), 345 small yellow perch, and 431 other fish representing 18 species were examined. All specimens were collected from an area widely used by spawning pike from Houghton Lake, Michigan. Organisms utilized for food by young pike included Entomostraca, insects (chiefly Chironomidae), tadpoles, minnows, darters, and other pike. As pike increased in size they passed through a definite feeding succession of Entomostraca to insects to vertebrates (chiefly fish). Cannibalism occurred, as shown by the fact that 13.3 percent of 354 pike 21 millimeters or more in total length had eaten other pike. Smallest pike found to be cannibals were 21 millimeters long. Competition between young pike and most other species of fish for invertebrate food was evident. The yellow perch was the most important fish predator of young pike. Competition for food, predation, and cannibalism undoubtedly were important factors in the high mortality of young pike in their first few weeks of life.

Introduction

In the past, most of the investigation of food habits of pike *(Esox lucius)* has been directed toward fish of comparatively large size with little attention being given to young individuals. The present report of the food habits of small pike and fishes associated with them covers one phase of the detailed life history study of pike conducted by the junior author at Houghton Lake, Roscommon County, Michigan, in 1939, 1940, and 1942. Field data for this report were collected during the spring and summer of 1939 and 1940 from the drainage ditches which enter Houghton Lake in the immediate vicinity of Peterson's Resort and which served as a spawning ground for adult pike and a rearing ground for the young. A description of these ditches, which drain surrounding marshes, has been given previously (Carbine, 1942). A count of adult pike migrating from the lake into the ditches was

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[1] Contribution from the Michigan Institute for Fisheries Research.

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made in 1939, 1940, and 1942. Accurate counts of young pike migrating from the ditches into the lake were also obtained during the first 2 years. In 1942, an estimate of the number of migrating young was made. These data (Carbine, 1944) are summarized as follows:

	1939	1940	1942
Number of spawning females......	125	65	56
Number of spawning males.......	280	81	70
Number of migrating young.......	7,239	1,495	8,000

Mortality of eggs and young pike on the spawning grounds was calculated to be 99.82, 99.93, and 99.56 percent for 1939, 1940, and 1942, respectively (Carbine, 1944). Although fewer eggs were deposited in the marshes in each succeeding year, observations indicated that large numbers of fry survived through hatching and the period of yolk absorption each year and that the survivors appeared to be as numerous in 1940 as in corresponding periods in 1939 and 1942. In each year the number of young observed dwindled before most of them had reached a length of 1 inch.

In each year pike fry began to migrate from the marshes and ditches into Houghton Lake when they had attained a length of about 20 millimeters, and a large percentage of the total number of migrants entered the lake within 6 weeks after hatching began. Some individuals remained in the ditches until late summer, when most of the former spawning area dried up. Along with the spawning pike, small yellow perch *(Perca flavescens)* and several other species of fish 2 to 4 inches in length, moved from the lake into the ditches and were present in the spawning area during the ensuing months. In the spring of 1939, these fish were allowed to enter the ditches for only 1 day and further entry was prevented by a weir. In 1940 and 1942 they were not hindered from entering the ditches during the entire period of investigation. This association of young pike with various other species is a natural condition which unquestionably had an important bearing on the survival and growth of the pike.

METHODS OF COLLECTION AND STOMACH ANALYSIS

Young pike, yellow perch, and 18 other species of fish were collected with seines, dip nets, minnow traps, and weirs. From May 6 to July 3, 1939, 33 collections of pike and 11 collections of other fish were secured. In 1940, 17 collections of pike and 13 collections of other fishes were obtained from May 6 to June 13. Species of fish other than pike collected in sufficient numbers for stomach analyses are listed in Table 1.

The total length of each fish was recorded to the nearest millimeter, and the stomach was removed and opened under a low-power, widefield binocular microscope. Food organisms were removed, identified, counted, and the volume of each kind of organism either measured by water displacement or estimated. In summarizing the data obtained, frequency of occurrence and percentage of total food volume were considered in determining the importance of various food organisms in the diets of the fishes concerned. Only those stomachs containing food were used in the calculation of the percentages of various food items in the stomachs. Qualitative examination of stomachs and intestines of pike and other fishes revealed that the contents of the two regions were very similar in most individuals. Therefore stomach contents alone were itemized in the food study.

Pike smaller than 40 millimeters in length were placed in 5-millimeter size groups, and larger individuals in 10- and 20-millimeter size groups. Analyses of food were made on a basis of these divisions. An individual food analysis was made for each collection of perch but other species were grouped together without regard for size or collection date.

SIZE AT WHICH PIKE BEGIN TO FEED

Fourteen fry 10 to 11 millimeters in length, collected in 1940, still carried a considerable amount of yolk and had taken no food. Two individuals 11 millimeters in length obtained in 1939 showed no trace of the yolk sac and had been actively feeding. One contained a *Chydorus* and a *Simocephalus;* the other, two *Chydorus,* two *Canthocamptus,* and one ostracod. Ten individuals 12 millimeters in length secured in 1939 showed no trace of yolk remaining and all had eaten several kinds of cladocerans, copepods, and ostracods. The number of food organisms per stomach ranged from 2 to 24. In 1940, two of four pike 12 millimeters in length still showed traces of yolk and had taken no food. The

TABLE 1.—*Species of fish collected for stomach analyses found associated with young pike.*[1]

Species		Year collected	
Common name	Scientific name	1939	1940
Yellow perch	*Perca flavescens* (Mitchill)	x	x
Bluegill	*Lepomis m. macrochirus* (Rafinesque)	x	....
Rock bass	*Ambloplites r. rupestris* (Rafinesque)	x	....
Pumpkinseed	*Lepomis gibbosus* (Linnaeus)	x	....
Brook stickleback	*Eucalia inconstans* (Kirtland)	x	x
Central mudminnow	*Umbra limi* (Kirtland)	x	x
Blackside darter	*Hadropterus maculatus* (Girard)	x	....
Iowa darter	*Poecilichthys exilis* (Girard)	x	x
Northern creek chub	*Semotilus a. atromaculatus* (Mitchill)	x	x
Northern redbelly dace	*Chrosomus eos* (Cope)	x	x
Western golden shiner	*Notemigonus crysoleucas auratus* (Rafinesque)	x	x
Brassy minnow	*Hybognathus hankinsoni* (Hubbs)	x	....
Bluntnose minnow	*Hyborhynchus notatus* (Rafinesque)	x	x
Northern common shiner	*Notropis cornutus frontalis* (Agassiz)	x	....
Blackchin shiner	*Notropis heterodon* (Cope)	x	....
Northern blacknose shiner	*Notropis h. heterolepis* (Eigenmann and Eigenmann)	x	x
Great Lakes spottail shiner	*Notropis h. hudsonius* (Clinton)	x	x
Rosyface shiner	*Notropis rubellus* (Agassiz)	x	x
Northern mimic shiner	*Notropis v. volucellus* (Cope)	x	x

[1] Identified by Walter R. Crowe.

TABLE 2.—*Occurrence of major groups of food organisms in stomachs of young pike collected in 1939.*

Size group (millimeters)	Number of pike	Entomostraca		Insects		Vertebrates		Average number of organisms per stomach
		Percentage of stomachs containing organism	Percentage of total food volume	Percentage of stomachs containing organism	Percentage of total food volume	Percentage of stomachs containing organism	Percentage of total food volume	
11—15	56	100.0	65.9	16.1	34.1	0.0	0.0	9.3
16—20	59	98.3	58.8	28.8	41.2	0.0	0.0	12.8
21—25	56	80.4	21.6	51.8	38.0	25.0	40.4	26.3
26—30	34	73.5	5.0	58.8	31.2	32.3	63.8	7.5
31—35	25	60.0	2.5	72.0	47.0	24.0	50.0	7.8
36—40	16	31.2	8.7	87.5	41.7	18.7	49.6	8.8
41—50	9	44.4	0.7	55.5	13.9	44.4	85.4	3.9
51—60	24	25.0	0.3	50.0	11.4	45.8	88.3	3.8
61—80	12	0.0	0.0	16.6	0.4	66.7	97.7	0.7
81—100	7	0.0	0.0	0.0	0.0	100.0	100.0	0.6
101—152	20	0.0	0.0	15.0	Trace	85.0	99.6	1.4

other two contained *Simocephalus* and *Chydorus* and had completely absorbed the yolk sac. Eight fry 13 millimeters in length had eaten quantities of copepods, cladocerans, and ostracods. One specimen contained 64 entomostracans, and a chironomid larva and pupa. Food organisms in the stomachs of these eight fry varied in number from 7 to 66. It appears that pike fry begin active feeding when they reach a length of 11 to 12 millimeters and may start even before the yolk sac is completely absorbed.

FOOD OF YOUNG PIKE

A total of 651 specimens was examined, of which 318 obtained in 1939 and 233 secured in 1940 contained food material. Data obtained from stomach examination substantiated observations of the voracious nature of the fry. Feeding apparently occurred in at least two habitats for not only were free-swimming organisms eaten, but judging from the number of chironomid larvae and ostracods in the diet, a considerable amount of foraging occurred on or near the bottom. Tadpoles and minnows were eaten as soon as the pike were large enough to handle them. Cannibalism began at a length of 21 millimeters and was especially frequent among the pike collected in 1939.

Food habits of young pike change as they increase in size and three feeding stages are evident during the period of change (Table 2). The first, extending from the time the fry begin to feed until they reach a length of about 25 millimeters, is one of feeding mainly upon entomostracans. In the second stage, which occurs during the period of growth from 26 to 50 millimeters in length, the food is mostly immature

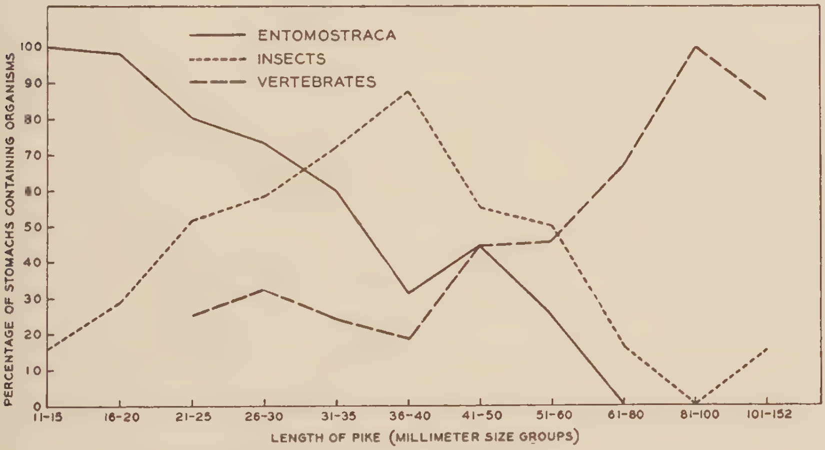

FIGURE 1.—Frequency of occurrence of major groups of food organisms in stomachs of pike collected in 1939.

TABLE 3.—*Occurrence of major groups of food organisms in stomachs of young pike collected in 1940.*

Size group (millimeters)	Number of pike	Entomostraca		Insects		Vertebrates		Average number of organisms per stomach
		Percentage of stomachs containing organism	Percentage of total food volume	Percentage of stomachs containing organism	Percentage of total food volume	Percentage of stomachs containing organism	Percentage of total food volume	
11—15	21	100.0	68.2	33.3	31.8	0.0	0.0	32.0
16—20	59	100.0	75.7	28.8	23.8	0.0	0.0	54.3
21—25	35	100.0	62.7	60.0	37.3	0.0	0.0	78.7
26—30	24	91.7	15.6	83.3	75.6	4.2	8.8	29.1
31—35	15	86.7	7.4	80.0	41.9	13.3	47.4	13.0
36—40	17	64.7	9.0	64.7	65.8	5.8	22.9	9.0
41—50	39	53.8	5.0	56.4	26.3	7.7	65.1	7.3
51—60	10	50.0	1.5	60.0	48.0	30.0	50.5	2.4
61—80	2	0.0	0.0	50.0	10.7	50.0	89.3	1.5
81—100	4	0.0	0.0	25.0	2.9	100.0	97.1	1.2
101—136	7	0.0	0.0	0.0	0.0	100.0	100.0	1.0

aquatic insects. In the third stage, characteristic of pike larger than 50 millimeters, the diet is composed almost entirely of fish and other vertebrates. There is a great deal of overlapping in the feeding habits of young pike of all sizes, but in general the feeding sequence, as fish increase in size, is Entomostraca to insects to fish. This sequence has been found to occur during the development of smallmouth black bass, largemouth black bass, yellow perch, white bass, and other predaceous fishes (Adams and Hankinson, 1928; DeRyke, 1922; Ewers, 1934; Forbes, 1888; Pearse, 1918; Surber, 1941; Tester, 1932; and others).

Close agreement in the relative quantities of major groups of food organisms entering into the pike diet in 1939 and 1940 is apparent in Tables 2 and 3. The same food trends are also evident for both years. This feeding succession is clearly shown in Figures 1 and 2.

Crustacean food.—Food first taken by young pike consisted primarily of cladocerans, of which the smaller forms, chiefly *Chydorus, Pleuroxus,* and *Scapholeberis,* predominated. Larger forms such as *Simocephalus* and *Eurycercus* were eaten more frequently by fish in the 21- to 25-millimeter group. *Daphnia* and *Bosmina* were eaten infrequently, and *Polyphemus* appeared only in stomachs collected on June 5 and 8, 1940. Copepods were a major food item for pike up to 26 millimeters long but rapidly diminished in importance as fish grew larger. *Cyclops* was most abundant in stomachs. *Canthocamptus, Diaptomus,* and *Osphranticum* occurred less frequently. Ostracods were eaten consistently, although in small quantities, by fish up to 70 millimeters in length. Stomachs of 77.4 percent of the pike under 21 millimeters and 39.1 percent of all those under 60 millimeters obtained in 1939 contained Entomostraca exclusively. In 1940, 68.7 percent of fish under 21 millimeters and 43.4 percent of those under 60 millimeters had eaten only Entomostraca.

Insect food.—Although insects formed an appreciable percentage of the total volume of food of pike from 11 to 70 millimeters in length, they were of greatest importance in the diet of fish between 26 and 50 millimeters long. Insect food consisted entirely of aquatic larvae, pupae, and nymphs. Midge larvae and pupae, principally chironomids, formed the bulk of the insect food. Beetle larvae, mayfly nymphs *(Blasturus* and *Ephemerella),* and dragonfly nymphs were consumed in small quantities.

Vertebrate food.—Tadpoles, which appeared in the ditches in late May, were eaten by all sizes of pike from 26 to 152 millimeters but were consumed much more frequently by larger specimens. These amphibians formed 7.6, 13.3, and 37.4 percent of the total food volume of all pike collected in both years in the 21 to 40-, 41 to 80-, and 81 to 152-millimeter size groups, respectively. Fish, other than pike, did not appear in the stomach contents of pike smaller than 51 millimeters but formed an increasingly large part of the food of larger specimens. Northern mimic shiner, rosyface shiner, bluntnose minnow, golden

TABLE 4.—*Comparison between the lengths of cannibal pike and pike found in their stomachs. Fish collected in 1939.*

Size group (millimeters)	Number of pike stomachs examined	Number of stomachs containing pike	Cannibal pike (Total length-millimeters)			Prey (pike) (Total length-millimeters)		
			Minimum	Maximum	Average	Minimum	Maximum	Average
21—25	56	14	21	25	23.3	11	17	14.1
26—30	34	11	26	30	27.8	12	20	15.1
31—35	25	5	31	35	32.4	13	18	15.6
36—40	16	2	36	37	36.5	15	20	17.5
41—50	9	0	....	....	....	....	....	....
51—60	24	4	52	60	55.6	8	30	13.2
61—80	12	2	74	78	76.0	44	45	44.5
81—100	7	1	94	94	94.0	20	20	20.0
101—152	20	1	102	102	102.0	....	....	....

shiner, creek chub, brook stickleback, and brassy minnow were identified in the stomachs.

Other pike formed the chief vertebrate constituent of the diet of fish 21 to 80 millimeters in length captured in 1939. Fourteen (25 percent) members of the 21- to 25-millimeter size group and 11 (32.2 percent) of those in the 26- to 30-millimeter group collected in 1939 had eaten other pike. Judging from the stomach contents, cannibalism was much more extensive in 1939 than in 1940. In the latter year only 7 stomachs of 233 examined contained other pike. Table 4 shows the extent of cannibalism in 1939 and the relative length of cannibal pike and those which were eaten. Minimum difference in length between predator (23 millimeters) and prey (16 millimeters) was 7 millimeters. The fact that young pike eat others of nearly two-thirds their own length is ample demonstration of their voracity and suggests that cannibalism is an important factor in reducing their own population.

Other food.—Few organisms, other than those previously discussed, appeared in the stomachs. Snails occurred in four specimens and Hydracarina in two individuals. Plant debris was found in a few stomachs of fish over 80 millimeters in length but was undoubtedly taken while capturing animal food.

Comparison of Food Use with Availability

In order to compare the plankton organisms found in the habitat with those found in the pike stomachs, four plankton samples (20 to 50 gallons of water strained through a plankton net for each sample) were obtained at the same time and place that collections of pike were made.

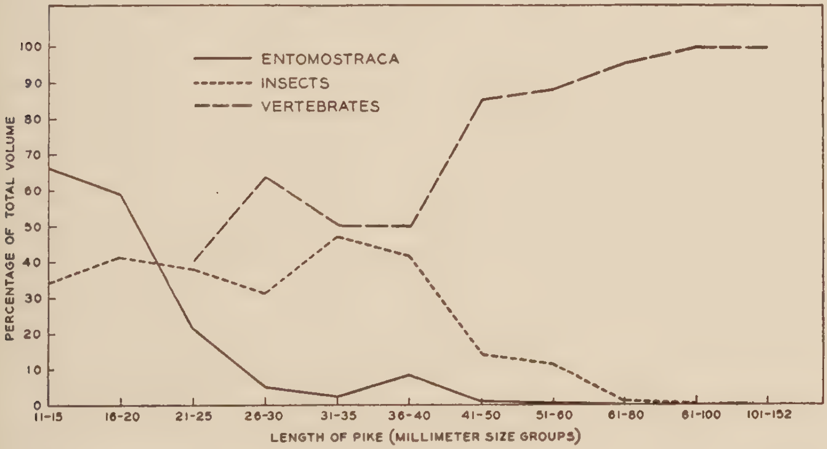

FIGURE 2.—Percentage of total food volume composed of major groups of food organisms in stomachs of pike collected in 1939.

TABLE 5.—*Comparison of Entomostraca eaten by pike with Entomostraca found in plankton samples—1940.*[1]

Date of collection	Number of stomachs with contents	Size range of pike (millimeters)	Stomach contents (Entomostraca)			Plankton sample (Entomostraca)		
			Organism	Total number of organisms in stomachs	Percentage of total number of organisms in stomachs	Organism	Total number of organisms in sample	Percentage of total number of organisms in sample
May 10	14	13—16	*Chydorus*	523	87.6	*Chydorus*	3,540	81.1
			Cyclops	35	5.9	*Cyclops*	255	5.8
			Simocephalus	22	3.7	*Bosmina*	180	4.1
			Canthocamptus	6	1.0	Nauplii	135	3.1
			Ostracoda	5	0.8	Ostracoda	120	2.8
			Scapholeberis	5	0.8	*Simocephalus*	60	1.4
			Bosmina	1	0.2	*Scapholeberis*	45	1.0
						Canthocamptus	30	0.7
May 11	8	13—14	*Chydorus*	121	69.5	*Cyclops*	1,243	44.7
			Pleuroxus	21	12.1	Nauplii	990	35.6
			Canthocamptus	14	8.1	*Chydorus*	370	13.3
			Ostracoda	12	6.9	*Canthocamptus*	104	3.7
			Cyclops	6	3.4	Ostracoda	44	1.6
						Pleuroxus	30	1.1
May 25	23	20—33	*Chydorus*	648	47.5	*Chydorus*	182	32.6
			Cyclops	373	27.4	*Cyclops*	109	19.5
			Pleuroxus	183	13.5	*Pleuroxus*	85	15.2
			Ostracoda	99	7.4	Ostracoda	61	10.9
			Simocephalus	40	2.9	*Canthocamptus*	61	10.9
			Diaptomus	10	0.7	Nauplii	36	6.5
			Canthocamptus	9	0.6	*Scapholeberis*	12	2.2
			Scapholeberis	1	Trace	*Bosmina*	12	2.2
May 28	8	25—29	*Simocephalus*	27	45.8	*Chydorus*	160	46.8
			Pleuroxus	12	20.2	Ostracoda	44	12.9
			Ostracoda	6	10.2	*Cyclops*	44	12.9
			Chydorus	4	6.8	*Pleuroxus*	19	5.4
			Cyclops	4	6.8	*Simocephalus*	15	4.4
			Osphranticum	3	5.1	*Canthocamptus*	15	4.4
			Eurycercus	1	1.7	*Bosmina*	15	4.4
			Scapholeberis	1	1.7	*Polyphemus*	15	4.4
			Diaptomus	1	1.7	Nauplii	15	4.4

[1] Plankton samples counted and organisms identified by L. Edward Perry.

Comparison of the relative abundance of various genera of Entomostraca in the plankton samples with those consumed by young pike shows that in two instances many of the microcrustaceans were eaten in direct proportion to their abundance (Table 5). In the other two cases much less agreement in relative abundance is evident. It is possible that on those dates on which relative numbers of organisms eaten and those in plankton samples showed little correspondence, the small number of stomachs collected did not give a representative picture of the feeding habits of the pike population at that time. It should be noted that nauplii, generally abundant in the plankton samples, were not found in the pike stomachs. Although the data are not conclusive, it appears that young pike are not selective in their feeding but tend to eat those organisms which are most abundant providing they are large enough to be of interest. Since Entomostraca are so important in the diet of pike in their first few weeks of life, it is probable that the abundance or scarcity of these organisms would be an important factor in the initial survival of the fry.

Effect of Food Habits on Growth Rate

Growth rate of pike (Carbine, 1942) showed a marked increase after the average length of fish had reached 44.2 millimeters in 1939 and 39.3 millimeters in 1940. Vertebrates and large insects formed the bulk of the food of fish in the 41- to 50-millimeter group in both years. The increased daily growth rate in June coincided with the appearance of larger food items (particularly fish) in the diet of pike collected at that time. Since increased growth rate occurred at the same time as the transition from invertebrate to vertebrate food, it appears that an accelerated growth rate is associated with the change to a vertebrate diet.

Competition Between Young Pike and Other Fish

That competition for various food organisms existed between the pike and other species of fish present in the ditches was clearly shown by analysis of the stomach contents of yellow perch (Tables 6 and 7) and other species of fish (unpublished). The degree of competition is evident in the relative abundance of various types of food in the stomachs of different species and different size groups of pike (Table 8). What bearing competition for food had on survival and growth of young pike cannot be determined since no information is available concerning the adequacy or inadequacy of the natural food supplies available. However, competition necessarily reduced the food supply and may have been a factor in the mortality of young pike.

Crustacean food.—Most species of fish ate entomostracans to some extent and competed with pike up to 40 millimeters in length for this food source. The brook stickleback, golden shiner, blacknose minnow, spottail shiner, and mimic shiner consumed considerable quantities of

TABLE 6.—*Summary of stomach contents of 95 yellow perch collected in 1939. Number of stomachs with contents 78, without 17. (L = larvae, P = pupae, N = nymph)*

Organism	Number of stomachs containing organism	Percentage of stomachs containing organism	Most organisms in any stomach	Average number of organisms in stomachs containing them	Percentage of total number of organisms	Percentage of total volume
Entomostraca	16	20.5	461	66.6	79.2	6.0
Cladocera	11	14.1	62	18.4	15.1	2.3
Copepoda	9	11.5	450	95.8	64.1	3.5
Malacostraca						
Amphipoda	3	3.8	3	1.7	0.4	Trace
Insecta	69	88.5	21	3.7	19.6	69.4
Diptera	20	25.7	18	6.3	9.4	13.8
Chironomidae (L)	8	10.2	3	1.5	0.9	1.0
Chironomidae (P)	13	16.6	18	7.9	7.6	10.5
Culicidae (L)	6	7.7	5	2.0	0.9	2.3
Ephemeroptera (N)	58	74.3	6	2.4	10.2	55.6
Coleoptera (L)	1	1.3	1	1.0	Trace	Trace
Vertebrates						
Pike	8	10.2	3	1.2	0.8	24.6

Average number of organisms per stomach 17.2.
Average volume per stomach in cubic centimeters 0.027.

TABLE 7.—*Summary of stomach contents of 547 yellow perch collected in 1940. Number of stomachs with contents 267, without 280. (L = larvae, P = pupae, N = nymph, A = adult.)*

Organism	Number of stomachs containing organism	Percentage of stomachs containing organism	Most organisms in any stomach	Average number of organisms in stomachs containing them	Percentage of total number of organisms	Percentage of total volume
Entomostraca	72	26.9	....	....	55.1	0.9
Cladocera	48	17.9	48	8.8	11.5	0.5
Copepoda	45	16.8	391	35.4	43.6	0.4
Ostracoda	1	0.4	2	2.0	Trace	Trace
Malacostraca						
Amphipoda	2	0.8	6	3.5	0.2	0.1
Insecta	201	75.3	83	7.2	42.7	29.1
Diptera	141	52.8	49	9.1	34.9	10.8
Chironomidae (L)	132	49.4	47	5.8	20.9	5.8
Chironomidae (P)	111	41.6	33	4.9	13.9	3.2
Culicidae (L)	3	1.1	1	1.0	Trace	0.1
Anthomyidae (L)	1	0.4	5	5.0	0.1	1.7
Odonata						
Anisoptera (N)	9	3.3	22	4.3	1.1	0.5
Zygoptera (N)	7	2.8	19	5.8	1.1	0.8
Ephemeroptera (N)	12	4.5	13	2.7	0.9	0.6
Ephemeroptera (A)	8	3.0	8	3.6	0.8	9.3
Trichoptera (L)	32	12.0	12	2.3	2.0	6.5
Coleoptera (L)	27	10.1	16	2.8	1.9	0.6
Vertebrates	67	25.1	3	1.1	2.0	69.8
Amphibia (Tadpole)	1	0.4	1	1.0	Trace	0.7
Fish	66	24.7	3	1.1	2.0	69.1
Pike	63	23.6	3	1.1	2.0	68.9
Cyprinidae	1	0.4	1	1.0	Trace	0.1
Fish remains	2	0.8	1	1.0	Trace	0.1

Average number of organisms per stomach 13.7.
Average volume per stomach in cubic centimeters 0.044.

TABLE 8.—*Comparison of food eaten by various size groups of pike with diet of other species of fish taken at the same time. Data collected in 1939 and 1940 combined.*

Species	Stomachs with contents	Entomostraca		Insects		Pike		Other vertebrates (Fish and tadpoles)		Algae and plant debris	
		Percentage of stomachs containing organisms	Percentage of total food volume	Percentage of stomachs containing organisms	Percentage of total food volume	Percentage of stomachs containing organisms	Percentage of total food volume	Percentage of stomachs containing organisms	Percentage of total food volume	Percentage of stomachs containing material	Percentage of total food volume
Pike (11-20 millimeters)	195	99.5	67.3	25.6	32.7	....	....	....	....	....	....
Pike (21-40 millimeters)	222	77.5	15.7	65.3	47.3	14.9	25.3	2.3	10.0	0.5	Trace
Pike (41-80 millimeters)	94	38.3	1.5	50.0	20.0	9.6	23.5	17.3	54.2	12.8	0.8
Pike (81-152 millimeters)	38	....	....	10.6	Trace	13.2	6.5	73.7	91.5	10.6	2.0
Yellow perch	345	25.5	1.7	78.3	35.4	20.6	62.0	1.2	0.7	....	....
Pumpkinseed	13	23.1	Trace	92.3	96.8	....	....	....	....	....	....
Bluegill	1	....	....	100.0	100.0	....	....	....	....	....	....
Rock bass	2	....	....	100.0	100.0	....	....	....	....	....	....
Brook stickleback	10	90.0	32.4	70.0	67.6	....	....	....	....	....	....
Mudminnow	19	31.6	4.5	68.4	59.1	....	....	5.3	4.5	31.6	Trace
Blackside darter	24	8.4	Trace	100.0	100.0	....	....	....	....	....	....
Iowa darter	46	43.5	3.8	93.5	96.2	....	....	....	....	4.3	Trace
Creek chub	11	....	....	63.6	7.9	9.1	1.4	18.2	76.2	9.1	14.4
Redbelly dace	36	30.6	Trace	55.6	21.2	....	....	....	....	38.9	78.8
Brassy minnow	20	....	....	....	....	....	....	....	....	100.0	100.0
Golden shiner	35	71.4	57.7	20.0	11.5	....	....	....	....	40.0	30.8
Bluntnose minnow	48	31.2	Trace	16.7	2.2	....	....	....	....	83.3	97.0
Common shiner	18	....	....	94.4	83.3	....	....	....	....	5.5	16.7
Blackchin shiner	20	20.0	4.4	80.0	81.5	5.0	14.1	....	....	5.0	Trace
Blacknose shiner	34	85.3	48.0	41.2	36.0	....	....	....	....	20.6	16.0
Spottail shiner	25	48.0	46.2	40.0	30.7	....	....	....	....	24.0	23.1
Rosyface shiner	14	14.3	4.7	100.0	95.3	....	....	....	....	....	....
Mimic shiner	55	47.3	16.0	38.2	36.9	3.6	14.4	....	....	43.6	30.4

entomostracans. These organisms occurred in 47.3 to 90.0 percent of the stomachs of these fish and formed from 16.0 to 57.7 percent of the total food volume.

Insect food.—Competition for insects between young pike and other fish associated with them was pronounced. Larvae and pupae, particularly those of Chironomidae, were consumed by all sizes of pike, yellow perch, and most other fish. Those fish which fed on chironomids extensively and thereby competed directly with pike, particularly those in the 21- to 50-millimeter size group, were: yellow perch, brook stickleback, mudminnow, Iowa darter, creek chub, golden shiner, redbelly dace, common shiner, blackchin shiner, blacknose shiner, spottail shiner, rosyface shiner, and mimic shiner. Effect of competition for insects, particularly chironomids, on the survival and growth of young pike cannot be accurately evaluated. Nevertheless, it is not improbable that the total competition for the insect food supply may have affected pike adversely during the insect-feeding stage.

Vertebrate food.—Very little competition existed between the pike and other fish for tadpoles and minnows. Yellow perch, mudminnows, and creek chubs consumed minnows to a limited extent and ate few tadpoles. If it is considered that young pike themselves are food for other pike, then perch would be a competitor of some importance for they decreased the number of pike fry available to the cannibals in the population.

PREDATORS OF YOUNG PIKE

In view of the small number of young pike that survived the first few weeks after hatching, there is no doubt that predation played an important role in the reduction of the population (Carbine, 1942, 1944). Perch and other fish present in the ditches consumed many young and the pike themselves were responsible in large measure for the reduction in numbers through cannibalism. Yellow perch (61 to 120 millimeters in total length) present in both years but more abundant in 1940 proved to be the most important fish predator. Of the 345 yellow perch stomachs which contained food, 71 (20.6 percent) contained one or more pike, which constituted 62.0 percent of the total volume of stomach contents. Most pike eaten by perch ranged from 12 to 36 millimeters in length (average length about 25 millimeters). The extent to which pike were eaten by perch in both 1939 and 1940 is shown in Table 9. Average length of pike eaten was about one-third of the average length of the perch which ate them and is probably near the maximum size of prey that these fish could eat with ease. By May 27, 1939 and June 8, 1940, the average length of pike was 44.2 and 38.3 millimeters, respectively; this fact suggests that the pike were reaching sufficient size so that perch were no longer able to feed freely upon them, and probably explains why no small pike were found in perch stomachs collected on May 23-24 and 27, 1939, and on June 8, 1940.

TABLE 9.—*Extent to which young pike were eaten by perch in each perch collection of 1939 and 1940.*

Collection date	Number of perch stomachs with contents	Percentage of stomachs containing pike	Percentage of total food volume composed of pike
1939			
May 9	52	7.7	3.0
May 12-16	2	0.0	0.0
May 20	6	66.7	88.2
May 23-24	11	0.0	0.0
May 27	7	0.0	0.0
1940			
May 13	25	8.0	19.2
May 22	5	40.0	94.3
May 27	14	14.4	65.7
May 28	45	22.2	87.5
May 29	15	13.3	51.8
May 30	19	36.8	95.9
May 31	32	25.0	76.1
June 1	31	45.2	87.0
June 2	16	25.0	73.9
June 3	13	30.8	75.0
June 4	7	28.6	83.3
June 5	20	30.0	63.8
June 8	25	0.0	0.0
Total	345	20.6	62.0

Of all other fish collected in 1939 and 1940, only the creek chub, blackchin shiner, and mimic shiner contained pike. It is not improbable, however, that most fishes associated with the pike fry consumed them to some extent. On May 8, 1942, the trap at the fry weir contained 21 pike, 5 pumpkinseeds, and 4 mudminnows. The pumpkinseeds contained a total of 12 pike and the mudminnows a total of 16. This high incidence was no doubt due to the availability of the pike fry in the trap.

Other animals such as birds, dragonfly and damselfly nymphs, beetle larvae, and water bugs (Belostomatidae) were observed to capture and eat young pike.

DISCUSSION AND CONCLUSIONS

It is evident from the data obtained that predation, cannibalism, and competition for available food between young pike and the fish associated with them in the ditches were factors in the high mortality rate of pike fry. The greater abundance of small yellow perch and other fish in the ditches in 1940 than in 1939 probably contributed significantly to the lower production of pike in 1940. Observations on the number of perch and other fish present in 1942 are incomplete; therefore no comparison with other years is possible.

In 1939 pike fry began to migrate from the ditches into Houghton Lake on May 12, 10 days after hatching, at an average length of 19 millimeters, and 85.4 percent of the total migrants moved into the lake in the succeeding 20-day period. In 1940, the first young (average length 23 millimeters) moved to the lake on May 25, 22 days after the first fry were observed in the ditches, and only 24.9 percent of the total run of fish entered the lake in the following 7-day period. The 12-day delay in the beginning of the lakeward migration of fry in 1940 offered greater opportunity for extensive losses in the ditches and marshes through predation, cannibalism, and other causes than in the previous year. Since more young moved downstream from the marshes to the lake on bright days than on cloudy days, an extended period of overcast weather, such as occurred in 1940, would offer more favorable conditions for losses from the causes mentioned above. A reduction in the number of predators in the spawning marshes may not necessarily result in a lessened mortality of young pike because cannibalism, known to be the chief cause of pike mortality in experimental ponds (Carbine, 1945), would still reduce the population to a low level.

Although competition, predation, and cannibalism unquestionably cause the loss of many young pike, other unfavorable conditions such as low water levels and limited spawning areas are no doubt of great significance in the survival of the young on the spawning grounds.

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Note on the Feeding Habits of the Giant White Marlin of the Pacific[1]

On June 22, 1950, an 851-pound white or silver marlin, *Makaira marlina* (Jordan and Hill), was brought into the Kyodo Fishing Co., Ltd., at Honolulu as part of the commercial catch of the long-line fishing boat "Monarch." The specimen had been cut in two about midway between the operculum and the caudal fin as is common practice aboard local long-line vessels to facilitate stowage of large fish. It was noted in this particular specimen, however, that the stomach and part of the large intestine had been torn appreciably, leaving a sizable gap in the abdominal cavity. According to information given by Shigeo Yamaguchi, captain of the fishing boat, the marlin was caught on one of the long lines, at a depth of about 60 fathoms, during fishing operations off Hana, Maui. When the fish was brought aboard it was observed that the abdomen was abnormally swollen, and upon cutting the fish for stowage, a big-eyed tuna (*Parathunnus sibi*) was found lodged in the stomach. The tuna had been caught on the long line first, for the hook still was set in the tuna's mouth when the specimen was removed from the stomach of the marlin. The marlin evidently had found the hooked tuna an easy prey and swallowed it head-first. It appears that the latter is a common feeding practice of the large spearfishes as noted by Nakamura (*Science of the Seas* [Kaiyo no Kagaku] 3(10), October, 1943). The tuna was removed from the stomach, and, since little digestive action had taken place, it was stowed as part of the catch.

When brought into the market, the tuna was found to weigh 158 pounds, although the anterior portion of the head was missing, having been cut off when the marlin was sectioned. It measured 1373 mm. in length from the posterior margin of the orbit to the cartilaginous part of the median caudal rays. From the two pieces of the marlin, an approximate length of 2994 mm. was obtained, as measured from the naris anteriorly to the median rays of the caudal fin posteriorly.

Although it has been previously noted (Nakamura, *op. cit.*) that the giant spearfishes can easily swallow adult skipjack, this is believed to be the largest single food item recorded for this group of fishes.—*Fred C. June, Pacific Oceanic Fishery Investigations, U. S. Fish and Wildlife Service, Honolulu, Hawaii.*

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NOTES

Two Juvenile Pointed-tailed Ocean Sunfish, *Masturus lanceolatus,* from Hawaiian Waters

JOSEPH E. KING[1]

The pointed-tailed ocean sunfish, *Masturus lanceolatus* (Liénard), is one of the "rare" marine fishes although it has been recorded from the tropical and subtropical areas of all oceans. In Gudger's review (1937*b*) of the natural history and distribution of the species, he reported only 59 authenticated records of the fish in the hundred years after its discovery in 1836. Strangely enough, of these 59 individuals there were 28 young and 31 adults, with no examples between the largest small specimen (60 mm. or 2.4 inches, standard length) and the smallest large specimen (30.5 inches, total length). Brimley (1939) has supplied records of five adult fish, ranging in size from 28 to 83 inches, that were not included in Gudger's report; four of these fish were from North Carolina waters, the fifth from Florida.

This wide gap between larval fish and adults was partially filled when three 6-inch juvenile fish were obtained from the stomach of a dolphin, *Coryphaena hippurus* L., taken in Florida waters (Gudger, 1938). Kuronuma (1940) described a juvenile *M. lanceolatus*, taken in a gill net in Japanese waters, which was 145 mm. in length from snout to caudal base and 259 mm. from snout to end of caudal fin. This interesting specimen differed from any previously described in that the caudal lobes was extended as a thin filament equal to approximately half the total body length.

Recently, Fitch (1950) reported that *M. lanceolatus* is found quite commonly in the stomachs of yellowfin tuna taken in Hawaiian waters, nearly a hundred specimens varying in size from ¼ inch to 2 inches having been obtained from this source. The only previous record of the species for Hawaiian waters is that of an adult fish, 37.3 inches in length, obtained from the Honolulu fish market in 1919 (Fowler, 1928).

The author has been unable to find in the literature any reports, except that of Kuronuma (1940), which describe or figure the caudal fin of *M. lanceolatus* as having more than a short lobe-like extension which may be pointed in the very young but in the adults is usually frayed or mutilated. From this characteristic shape of the caudal fin the fish has derived its scientific name, *Masturus lanceolatus* [Gr., *mastos*, breast or nipple; Gr., *oura*, tail; L., *lanceolatus*, a little lance = the nipple-tailed, lance-tailed fish (Gudger, 1937*a*)].

On April 11, 1950, during long-line fishing for tuna by the Fish and Wildlife Service research vessel *Hugh M. Smith*, a dolphin (1,100 mm. fork length) was taken just west of the island of Hawaii at 19° 30′ N. Lat.–156° 05′ W. Long. In the dolphin's stomach were two 5-inch *M. lanceolatus*, one in good condition, the other with a gash on each side. Both specimens (in alcohol) are generally similar in coloration to the 6-inch fish described by Gudger (1938). They are dark gray dorsally, shading into milky-white on the lower two-thirds of the body. They have the typical gray spotting below the eyes and pectoral fins and posteriorly above the anal fin.

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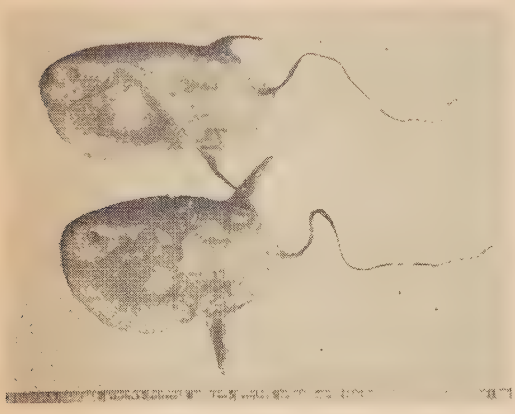

FIG. 1. Two juvenile *Masturus lanceolatus* taken from the stomach of a dolphin captured in Hawaiian waters. April 11, 1950.

These fish differ in one important respect, however, from any previously collected. Each has the caudal lobe continued as a whip-like structure longer than the body of the fish (Fig. 1). Except for the proximal 2 or 3 centimeters, this caudal extension is very fragile, almost paper-thin, and is frayed toward the tip. These may be the first observed specimens—at least among the post-larvae, juveniles, and adults—to show the true "normal" or unmutilated nature of the caudal fin. In view of the delicate structure of this appendage it is easily seen why the appendage is usually greatly reduced or missing in juvenile and adult specimens.

Measurements of the two fish, fin ray counts, etc., are given in the accompanying table:

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TABLE 1

MEASUREMENTS AND FIN-RAY COUNTS OF TWO JUVENILE POINTED-TAILED OCEAN SUNFISH (LENGTH AND DEPTH IN MILLIMETERS)

SPECIMEN	LENGTH TO			DEPTH			FIN-RAY COUNT				
	Base C	Edge C	Tip C	Behind eye	Before D & A	Over D & A	P	D	C	A	D+C+A
Good condition	111.9	135.0	300	59.8	63.6	121	10	20 (19?)	5+6+8	19 (18?)	58
Gashes in both sides	107.2	129.0	317	68.2	68.6	135	10	19 (18?)	5+6+7	18	55

DISTRIBUTION OF NEMATOPSIS INFECTION ON THE OYSTER GROUNDS OF THE CHESAPEAKE BAY AND IN OTHER WATERS OF THE ATLANTIC AND GULF STATES[1]

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INTRODUCTION

Nematopsis, a sporozoan parasite in the tissues of oysters and in the digestive tracts of crabs, has a wide distribution. Frequently found in the oysters from many states, it seems to be especially abundant in southern waters. The microorganism is apparently harmless to humans who consume shellfish; the effect on its hosts has not yet been adequately studied.

Several years ago the infection of oysters by Nematopsis occupied a prominent part in the arguments at the litigation of a group of Louisiana oystermen against an oil company operating in southern waters (See Case No. 37036, Southern Reporter 1944, [1] 750 2nd No. 4, pages 340-349). Because of the assertions made in the court, that Nematopsis is harmful to oysters, the authors thought that data on the distribution of the parasite, combined with the observations on the quality of the meats of the infected and noninfected oysters, and with the data of oyster mortalities, may be useful in evaluating the biological importance of this microorganism.

In a study of the distribution of Nematopsis attention was given to the questions whether the infection impairs the quality of the meat of the oysters, and whether the presence of spores in their tissues may be correlated with the mortality of oysters in their natural environment. Observations in Chesapeake Bay were made in connection with the work on the ecology and oyster culture that the Service conducts in this body of water jointly with the Maryland Department of Tidewater Fisheries, and Virginia Fisheries Laboratory. The authors had, therefore, an opportunity to obtain information regarding the productivity and quality of the oysters from various bars, and to be notified immediately of any abnormal conditions that may have been noticed in any part of the Bay. Scattered data regarding the distribution of Nematopsis in other waters have been summarized in the second part of the paper from personal observations of the authors, or from the data supplied by others.

The study of the distribution of Nematopsis in Chesapeake Bay was made by Landau, with the assistance of the personnel of the Maryland Department of Tidewater Fisheries who frequently provided boats for field trips. The work in the Bay began early in June and extended through September 1946. Additional data were collected, however, prior to and since those dates.

The authors are grateful to the officers of the Maryland Department of Tidewater Fisheries for their cooperation and help, and to Dr. James

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[1] Published by permission of the Director of the Fish and Wildlife Service.
[2] Now with the U. S. Navy Hydrographic Office.

Nelson Gowanloch, Chief Biologist of the Louisiana Fish and Wilf Life Service for making available to them valuable data on the distribution of Nematopsis in Louisiana waters.

TAXONOMIC POSITION AND HOSTS

Nematopsis, a sporozoan of the family Gregarinidae, was discovered in 1892 by Schneider, who described the cysts of this microorganism in a razor clam, Solen. Leger and Duboscq (1913) experimentally hatched the cysts resembling those of Nematopsis. They regarded the microorganism as Porospora, and referred to the cysts as the Nematopsis stage of this genus. Hatt, in 1931, arrived at the conclusion that there are two distinct genera, Porospora and Nematopsis, the latter having monozoic thick-walled cysts, while Porospora has spores in phagocytes, without protective walls.

The occurrence of Nematopsis in the United States was first noticed by Prytherch (1931), who found the oysters in certain sections of Virginia, North Carolina, and Louisiana heavily infected with cysts of this parasite. Prytherch (1938) and Kudo (1939), when working in 1936 at U. S. Fisheries Station, Beaufort, North Carolina, reported separately that they traced the life cycle through the two hosts, the Xanthid crabs, in which the developmental stages of the gregarine are completed, and the oyster, in which the spores encyst in a resting state.

Kudo (1939) includes the Nematopsis found in American oysters with the European species, *Nematopsis legeri.* Prytherch (1940), however, describes it as a new species under the name of *Nematopsis ostrearum*. The question has not yet been definitely settled and requires further study.

METHOD

In the course of the field work in Chesapeake Bay, samples were collected from 74 natural oyster bars located in all the major tributaries and in the Bay itself. Oyster populations on these bars consisted exclusively of native stock, i.e., the oysters which set and grew naturally on these bottoms. Planted areas were excluded from the study because of the impossibility of determining the exact time the oysters were moved, and ascertaining whether they had been already infected before they were transplanted.

In each tributary of the Bay, a series of sampling stations was established over the entire salinity gradient of the stream, i.e., from its mouth, where the concentration of salts was usually the greatest, to the upper limits of oyster growing area, where the salt content of the sea water was greatly reduced by river discharge. Likewise, the sampling area of the Bay proper, extended from the section of high salinity at Hampton Roads in the lower part of the Bay, to South Tea Table, the most northerly oyster bar, located in the upper part of the Bay which is greatly affected by the discharge of fresh water.

At each station, record was made of the depth of water, composition and consistency of bottom sediment, salinity of water at the bottom, and the density of the oyster population. Except in the shallow water stations where tongs were used, oysters and mud crabs were collected with a small thirty-two inch dredge. Oysters were taken to the laboratory and kept at 40° F. until the examination of their tissues was completed. Crabs were preserved in alcohol, the strength of which was gradually increased from 30 to

70 percent. (This precaution was necessary to avoid too rapid a dehydration which makes the hard parts of crabs too brittle).

Since Nematopsis may infect various crabs, other than Xanthidae, note was taken of any species that occurred over oyster bottoms frequently or in great abundance, and which might be suspected as a possible carrier of the parasite.

Samples of water collected at the desired depth were kept in tightly closed bottles until they were returned to the laboratory, where their specific gravity was determined by hydrometer. The character of the bottom was recorded by the feel of the lead-line and by observing the material brought up in the dredge. In accordance with the size and appearance of their shells, oysters were divided into the following four classes: (1) One year old or younger; (2) Two to three years old; (3) Over three years old, and (4) Very old. After opening them in the laboratory, the condition of the meats of each oyster was recorded as "good", "fair", or "poor", depending on its appearance, firmness and color.

Since we noticed in our preliminary studies in the Chesapeake Bay region that most of the cysts were found in the mantle, and the other organs were infected only in severe cases, the mantle alone was examined regularly. When infection was heavy, the muscle, heart, gills and palps were also examined. We found that in the latter cases the adductor muscle was frequently infected, but never as heavily as the mantle. The heart, gills and palps very rarely contained cysts. Very heavy infection of gills was observed, however, in the oysters from Alabama and Texas. Dying oysters, or those that seemed weak or abnormal, were studied in greater detail and all their organs were examined.

For counting the cysts, the following technique was employed: a piece of tissue a few square centimeters in area was cut from the posterior ventral edge of the mantle and pressed with a few drops of 10% KOH between two microscope slides until it was sufficiently thin so that no cysts could be obscured by overlying tissues. Then the preparation was examined at 100X magnification. For each oyster, the cysts were counted in fifty microscope fields of pressed tissue. The area of the mantle thus examined extended from the tentacular edge to about 5 mm. inward. This covered the main zone of infection as well as some of the adjacent portion of the mantle. In the preparations of oyster spat, the entire specimen was mounted and examined. The number of cysts were recorded for each slide. An average count for the ten oysters, constituting a sample, was made and the number of cysts was computed for square centimeter of the area of the mantle compressed between the two slides. This figure was used as an index of the intensity of infection.

For histological study, oyster tissues were preserved in Allen's modification of Bouin's fixing solution, imbedded in paraffin, sectioned, and stained with Mallory's triple stain, hematoxylin, and eosin or safranin.

Mud crabs were identified to genus.* They were then dissected and the hind-gut split open and examined for gregarine stages of the parasite.

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* A special key to the Chesapeake Bay Xanthid crabs was prepared by Dr. Waldo Schmitt of the National Museum, Washington, D. C. Doubtful identifications were checked by Dr. F. A. Chace of the National Museum, and by Dr. E. Kronin of the Chesapeake Biological Laboratory, Solomon's Island, Maryland, whose assistance is gratefully acknowledged by the authors.

DISTRIBUTION OF NEMATOPSIS IN CHESAPEAKE BAY—

PERCENTAGE OF INFECTED OYSTERS

In a study of the distribution of any parasite, it is of interest to determine the percentage of the population infected as well as the intensity of the infection. In the present investigation, both factors were determined for each bar and the data summarized in a table placed at the end of this paper (Table 6). To facilitate graphical presentation of the results, the occurrence of Nematopsis in the oyster populations of different bars was plotted on the map reproduced in Fig. 1. The data were grouped in four classes, indicated by the following symbols: Noninfected oysters are shown by an open circle; from 1 to 25 percent infected—by a circle with one quarter blacked; from 25 to 50 percent infected—by a circle with one half blacked; 50 to 100 percent infected—by a black circle.

Inspection of Fig. 1 discloses a widespread distribution of Nematopsis throughout the oyster grounds of the Bay. Changes in salinity of water apparently present no barrier to the distribution of the parasite, for in the lower part of the Bay where salinity of water is higher, the oysters are as generally infected as those in the upper part of the Bay, where, due to the river discharge, the sea water is greatly diluted. The same holds true for various tributaries of the Bay. The results are not, however, unexpected since both hosts of Nematopsis, the Xanthid crabs and the oyster are euryhaline species, capable of withstanding great fluctuations in the concentration of salts.

The upper part of the oyster-producing area of the Potomac River appeared to be less infected than any other tributary of the Bay. Four bars of this section, namely, I-6, I-7, I-8, and I-9 (Fig. 1) were either free of Nematopsis, or contained less than 50 percent infected oysters. The remaining five bars in the lower part of the Potomac were, however, more than 50 percent infected. What ecological factors are responsible for a relative freedom from infection in the upper part of the Potomac remains undetermined.

INTENSITY OF INFECTION

The intensity of Nematopsis infection, expressed as a mean number of cysts per square centimeter of mantle tissue, varied from 0 to 3546. The data were obtained for each station and are summarized in Table I showing the mean and the range of variation in each sampling area. It is apparent from an examination of this table that the greatest intensity of infection is found in James and York Rivers. This may be due to the fact that adult oysters are not permitted to be taken from the public seed grounds, which constitute the major portion of oyster bars of the James River, and therefore the oyster population remains exposed to the infection for longer periods of time than on bars open to commercial fishery. This tentative explanation may also apply to the York River, where the taking of oysters for commercial fishery has been discontinued on account of the industrial and domestic pollution of water.

Salinity apparently is not a controlling factor. While highest intensity of infection occurred in the waters of 14 to 16 o/oo salinity, infections of lesser intensities were observed throughout the range from 0 to 20 o/oo.

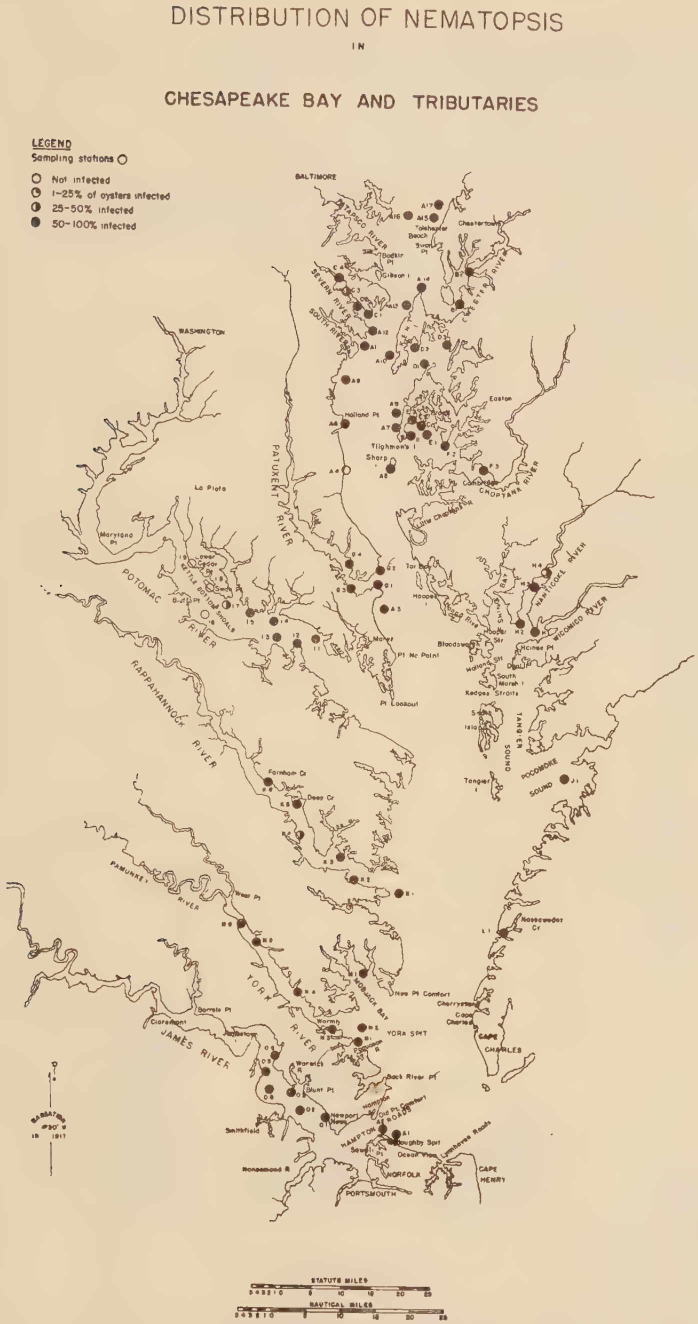

Figure 1. Sketch map of the Chesapeake Bay and tributaries showing the distribution of Nematopsis over the principal oyster bars in 1946-1947.

Likewise, there was no correlation between the intensity of infection or its frequency and the character of the bottom. A greater percentage of very heavily infected oysters was found on soft bottom but the trend was not consistent.

TABLE 1. AVERAGE INTENSITY OF NEMATOPSIS INFECTION BY AREAS

Name	Number of Stations	Number Cysts per square Cm. Min.	Max.	Mean
Chesapeake Bay	21	0	653	193
Chester River	2	40	93	66
Severn River	4	1	259	90
Eastern Bay	4	26	340	179
Harris Creek	3	11	38	21
Choptank River	3	9	26	16
Patuxent River	4	3	53	24
Nanticoke River	4	1	5	4
Potomac River	9	0	11	2
Pocomoke Sound	1	----	106	----
Rappahannock River	6	1	213	78
Nassawadox Creek	1	----	738	----
Mobjack Bay	1	----	342	----
York River	6	22	2118	482
James River	6	8	3546	1437

Four of the bars studied were revisited 3 to 4 months after the completion of the first examination. There was no signficant difference in the percentage of infected oysters, but on two of the bars the intensity of infection was found to be much higher than during the first test (Table 2).

TABLE 2. INTENSITY OF NEMATOPSIS INFECTION ON FOUR BARS IN FEBRUARY - MARCH AND IN JUNE, 1946

Location	Station	Date 1946	Intensity (Cysts per square cm.)	Percentage infected
Wire Ground	A-9	March 21	8.2	90
Wire Ground	A-9	June 25	151.1	100
Gum Thicket	A-10	March 4	317.4	100
Gum Thicket	A-10	June 25	581.9	100
Tolchester	A-15	Feb. 28	11.8	100
Tolchester	A-15	June 27	14.3	100
S. Tea Table	A-16	Feb. 28	4.7	70
S. Tea Table	A-16	June 27	69.5	66

INTENSITY OF INFECTION AND AGE OF OYSTERS

After invading the oyster tissues, the Nematopsis spores remain inactive until the oyster is eaten by a crab and its tissue digested. It is therefore logical to expect that adult oysters would contain a greater number of cysts than young ones. This conclusion was fully confirmed by the observations in the Bay. The relationship between the age of the oysters, intensity of infection, and percentage of infected oysters is presented in Fig. 2, in which all the records of examination of tissues are grouped in the three age classes, namely, spat, young oysters (less than three inches long) and adults (three inches and larger). Examination of this diagram shows that over 80 percent of spat was either free of infection, or only slightly infected. Intensity exceeding 1000 cysts per square inch of mantle tissue occurred only in the adult oysters. It is clear that the intensity of infection of individual oysters is cumulative and increases with their age.

INTENSITY OF INFECTION, CONDITION OF MEAT, AND MORTALITY OF OYSTERS

Oysters on each particular bar were generally in a uniform condition of health and fatness. This may be attributed to the fact that environmental factors which primarily determine the degree of fatness and the rate of growth of the oyster were uniform over the bar. Individual variations occurred occasionally but could not be correlated with the abundance of

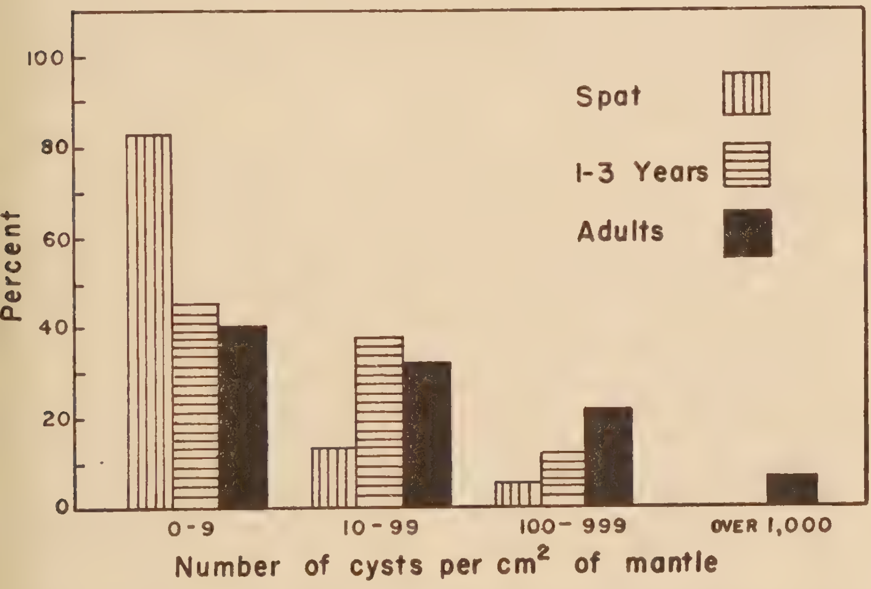

Figure 2. Intensity of infection and percentage of spat, young and adult oysters in the Chesapeake Bay and tributaries infected by Nematopsis. Intensity of infection is expressed in the number of cysts per square centimeter of mantle tissue.

Nematopsis cysts in the tissues. In general, the infection was not consistently lower in good oysters than in poor ones. These results agree with the observations made previously in the York River by Galtsoff et al., (1947).

During the course of the investigation there was no unusual mortality among oysters that could be attributed to the Nematopsis infection. There was also no evidence of any harmful effect of the parasite on the general condition of the oysters. We saw no symptoms of the failure of the adductor muscle, or of the tendency of the mantle to withdraw. The latter condition leads to the abnormal development of the shell, which was not noticeable among the Chesapeake Bay oysters.

Microscopical analysis of infected tissues showed the cysts lying in large interstitial spaces between the connective tissue fibers where they apparently do not interfere with the normal functioning of the organs. There was no inflammatory reaction of the surrounding tissues as one would expect to find as a result of action of toxins or because of physical irritation of tissues and occlusion of blood vessels. The observations are not surprising since the parasite is in a resting stage and does not grow or propagate within the oyster.

ABUNDANCE OF CRABS

Accurate counts of mud crabs were not feasible, since no practical method of collecting them quantitively has been developed. Too many factors interfere with the possibility of obtaining a sample representative of crab population. The crabs crawl among the shells and oysters and rest in crevices. Many of them find shelter in the so-called "boxes", i.e., intact shell-pairs from which the meat has been eaten or decomposed. The crabs usually stay in the depression of an oyster or clam shell at the hinge end of it. Crabs which hide in empty shells are more easily captured than those which crawl freely. The number of crabs caught in a dredge is not therefore a measure of their abundance.

The genera most frequently caught were *Rhithropanopeus* and *Eurypanopeus; Panopeus* was rather rare. According to Prytherch the latter two are the vectors of the parasite.

Samples of preserved crabs from each station were dissected and examined for the presence of gregarines in the hind gut. A few unpreserved crabs were examined to check the possibility that the gregarines may have been disintegrated beyond recognition by the action of the killing fluids. Again, no parasites were found.

In view of the widespread distribution of Nematopsis these results are surprising. The feeding periods of these crabs are not well known. It is plausible, therefore, to suppose that they were not infected because they had not been eating oyster meats. Since the crabs were studied during one season only, it is possible that some other factor has interfered with the relationship between the parasite and its host. It is also possible that there is some other carrier in Chesapeake Bay. These questions can be answered only by further study.

Several blue crabs, Callinectes, and occasional oyster crabs, Pinnotheres, were found. They were not, however, sufficiently widespread or numerous to be significant.

OCCURRENCE OF NEMATOPSIS IN ATLANTIC AND GULF STATES

MASSACHUSETTS AND RHODE ISLAND

In the course of studies of the biology and physiology of the oyster, conducted for many years by Galtsoff at Woods Hole, Massachusetts, many hundreds of oysters were examined microscopically, using both living and preserved material. So far, Nematopsis has not been found in the oysters from Cape Cod area, including Buzzards Bay, Martha's Vineyard Sound, Chatham Bay and the bays on Martha's Vineyard Island. Likewise, Nematopsis cysts have not yet been observed in the adult oysters from Narragansett Bay.

NEW YORK AND CONNECTICUT

In 1942, 30 percent of the 3-year old oysters (set of 1939) transplanted from New Haven area of Long Island Sound to Great South Bay, were found by Galtsoff to be lightly infected with cysts. In this case, the infection was primarily confined to the anterior part of the adductor muscle and no cysts were found in the mantle. The Great South Bay set of 1941, examined at the same time, was free of infection. It is possible that Nematopsis has been introduced into northern waters from the south with the seed oysters brought in for planting. For instance, it was learned by Galtsoff that in May 1941, oysters from one of the bars in Delaware Bay were planted in Great South Bay, New York. The fact that the oyster population of this bar is infected was established only in the fall of 1942. Through the cooperation of the interested oyster company it was possible to trace the fate of the Delaware seed planted in New York waters. In the fall of 1942, 70 percent of them were found to be infected; the principal site of cysts being both parts of the adductor muscle. The record of the company shows that in 1941 and 1942 growing conditions in Great South Bay were very good and the Delaware Bay oysters developed very well without any unusual mortality.

DELAWARE

The presence of Nematopsis in oyster grounds in Delaware Bay was first established by Galtsoff in September 1942. About 60 percent of adult and young oysters from Leipsic Creek were found mildly infected by spores located mostly in the adductor muscles. Further observations made by Frey, are summarized in the following table:

TABLE 3. OCCURRENCE OF NEMATOPSIS IN 1942 AND 1943 YEAR CLASSES OF OYSTERS FRON DELAWARE BAY, OCTOBER 27, 1943.*

	1943 year class		1942 year class	
Seed Bed	percent infected 1/	total cysts 2/	percent infected 1/	total cysts 2/
Ridge	100	44	80	81
Red Buoy	0	0	20	3
Over the Bar	50	90 3/	90	20
Thrum Cap	20	2	90	23

1/ 10 oysters in each sample
2/ 50 low power fields each of smooth muscle and striated muscle
3/ 79 cysts were found in one spat
* (unpublished data on file of Fish & Wildlife Service.)

Nematopsis was widely distributed among the 1942 year class, although infestation was generally light. Observations repeated by Frey in March 1943, showed the presence of parasitized oysters on all the five bars (Silver, Thrum Cap, Over the Bar, Red Buoy, Ridge Bar) that were examined at this time. Heaviest infection was found in oysters of Over the Bar reef. The site of infection was primarily the striated part of the adductor muscle and the labial palps.

Moderate infection of oysters in Rehoboth Bay, Delaware, was reported in February 1947, by Chipman and Engle (unpublished report in file of the U. S. Fish and Wildlife Service). Infected oysters were found at the following places: Mouth of Lewes Canal, North end of Bed No. 3, Mouth of Love Creek and Mouth of Herring Creek. Counts of cysts made by Landau showed a variation from 19 to 1924 cysts in 50 fields (100 x) of mantle tissue.

Chipman and Engle reached the conclusion that Nematopsis was not damaging the oysters of the Bay.

LOUISIANA AND MISSISSIPPI

When in September 1941, an extensive mortality among planted oysters was noticed in the areas west of the Mississippi River, the Louisiana Department of Conservation made an attempt to ascertain whether this mortality was correlated with the presence of Nematopsis. During the first week of October, Dr. Kavanagh, Biologist of the Division of Oysters and Water Bottoms of the Louisiana Department of Conservation, visited some of the principal oyster-producing grounds west of the mouth of the Mississippi River in Jefferson and Plaquemines Parishes which were affected by the mortality. By interviewing the lessees and examining the oysters gathered from their locations, he confirmed the reports regarding the mortality of oysters and obtained information about the origin of planted oysters, and the time they were planted. During the last week of the same month, Kavanagh examined the grounds east of the Mississippi River which were not affected by the mortality. The latter area comprises the principal public oyster bottoms of the state which are not leased to private persons but are open for fishing to Louisiana and Mississippi oystermen. At this time no mortality of oysters was observed or reported from this area, the trouble being apparently confined to the west of the river and particularly to Barataria Bay and adjacent bayous.

It is a common practice of the oyster growers in Louisiana to obtain seed from the grounds east of the river and to plant them on their leased bottoms on the west side of the delta. Planting is carried out usually in April and May, although the practice is not universally observed and some of the planters bed their seed oysters in August or November. Oysters which perished during the fall of 1941 had been planted in 1939 and 1940; they remained in the new locations from 8 to 16 months. This proves that their mortality was not due to the exposure and shock incidental to planting since no unusual losses among them were noticed during this period.

For microscopic examinations, samples, comprising twenty specimens, were taken from each locality and preparations were made of a portion of the gills of each oyster.

Table 4 summarizes essential information taken from Kavanagh's unpublished report. It shows that the mortality on the grounds west of the Mississippi varied from 50 to 80 percent, and, with the exception of one locality (Shell Island Bay), no mortality was noticed east of the river. There was no apparent relation between the infection of oysters by Nematopsis and the extent of mortality on various grounds. The mortality stopped sometime in September, for no dying oysters were observed in October. Yet, at this time, on several grounds oysters were heavily infected by Nematopsis.

TABLE 4. SUMMARY OF OBSERVATIONS ON THE INFECTION OF OYSTERS BY NEMATOPSIS MADE BY L. D. KAVANAGH IN LOUISIANA—OCTOBER 1941.

Location	Percent Mortality	Percent Infected Light	Medium	Heavy
Scofield Bay	50		100	
Cyprian Bay	50		100	
Cyprien Bay	50	50	50	
Bay Pomme d'Or	50	70	10	20
Shell Island	50		20	80
Bayou Fontenelle	50	10	10	70
Bayou Ferran Michel	50	10	40	50
Bastian Bay	50	10	40	50
Grand Bayou	50	90	10	
Bay Robinson	70	10	40	30
Bayou Chalund	80		30	70
Bayou La Vigne	80		50	50
Balich Bay	85		60	40
Bayou Catherine	85		60	40
Bay Ronquille	75	30	60	10
Barataria Bay	80	10	80	10
Bay des Islettes	66			100
Bay Wilkinson	0	0	0	0
Bayou St. Denis	0	0	0	0
Bay Malnomme	(1)	60	40	0
Bay Chene Fleur	0	0	0	0
EAST OF THE MISSISSIPPI RIVER				
Jackass Bay	0	0	60	40
Bayou Long	0	0	70	30
Bay de la Berge	0	0	40	60
Shell Island Bay	75	0	30	70
American Bay	0	30	50	20
Baker's Canal	0	10	20	10
Johnson Bayou	0	0	40	60

(1) No unusual mortality was observed

In 1947, when making a study of the hurricane damage to oysters, Engle found Nematopsis at the following stations in Mississippi Sound (Table 5).

TABLE 5. THE OCCURRENCE OF NEMATOPSIS IN THE LOUISIANA PART OF THE MISSISSIPPI SOUND IN DECEMBER 1947.

(From unpublished data of James B. Engle)

Station	Average number of cysts per field	Bottom	Meat
Half Moon Island	200	hard, shell	Good
Grand Pass, North entrance	27-30	hard, shell	Fair
Deep Water Pass	138	hard, shell	Fair
Cranetown Bay	120-168	hard, shell	Good
Martin Island, Chandeleur Sound	27-320	hard, shell	Very good

Fairly heavy infection was found in some of the oysters at Cranetown and in Chandeleur Sound. The condition of their meats was, however, good.

In the western part of the Mississippi Sound, the areas immediately adjacent to Little Dauphin Island, including the Dauphin Island Bay, contain oysters, very heavily infected by Nematopsis (Engle, 1945).

ALABAMA

In Mobile Bay, Alabama, an extraordinarily heavy infection with Nematopsis spores was encountered by Engle (1945) at Cedar Point Reef. Samples shipped to College Park, Maryland, Laboratory were examined by Galtsoff. In this case the cysts were so abundant in the gills of the oyster that they completely obscured the tissue and clogged the water tubes of the gills. Oysters from other parts of Mobile Bay were only lightly infected. There was no unusual mortality among the heavily infected or lightly infected oysters.

TEXAS

The occurrence of Nematopsis in Texas waters is widespread. Infection of oysters of Gopano Bay was recorded by Galtsoff in January 1942, (unpublished report in files of the Fish and Wildlife Service). On Jordan's Run about 40 percent of the oysters contained cysts. Some of the specimens were so highly infected that virtually all the organs examined (mantle, gills, muscle, heart and labial palps) contained cysts. One hundred percent of oysters on Lap Reef were found very heavily infected, their organs and tissues containing countless cysts. The condition of the oyster meats was poor.

Oysters from Two by Four and Borup reefs examined at the same time were found also infected but the condition of their meats varied from fair to good. Some of them had a gonad layer about 3 mm. thick. Heaviest infection was found in the gills.

Mesquite Bay is known for the quality of its oysters. In January 1942, all the oysters taken for examination were found to be heavily infected with Nematopsis, especially in the gills. The appearance of these oysters was, however, good and there was a considerable deposit of glycogen in the mantle.

In Matagorda Bay area, Nematopsis was recorded from the Lake, in Palacios Bay, and Karankawa Reef. In 1942 the infection on these grounds was widespread (100%) but light and confined to the adductor muscle.

In 1947, some of Texas grounds were revisited by Galtsoff, who again found heavy infection of oysters of Copano Bay. Not only the mantle was heavily infected, but in some of the specimens the blood vessels and water tubes of the gills were full of cysts. Two months before this examination was made, some of these oysters had been transplanted from Copano Bay to Aransas Bay. In comparison with those remaining in Copano Bay, the transplanted stock showed great improvement in growth and in deposition of glycogen although all the oysters were heavily infected. This experiment, conducted by the Texas Game, Fish and Oyster Commission, shows that Nematopsis infection does not prevent the improvement in quality of meat if the oysters are transplanted to better grounds.

South Bay, near Port Isabel, is the southernmost location in the United States where the eastern oyster is grown for market. Samples comprising twenty-four oysters, shipped in May 1947, by Dr. J. W. Hedgpeth to College Park, Maryland, were found moderately infected by Nematopsis. The condition of meat was good (solids 16% and glycogen 7.2% of dry weight).

FLORIDA

On the west coast of Florida, Nematopsis cysts were found by Galtsoff in the oysters near Pensacola (March 1946), and Fort Myers (April 1946). In all instances, the infection was light. Unfortunately, no data are available regarding the presence of Nematopsis in Apalachicola Bay, the principal area of commercial oyster fishery of the State. On the east coast of Florida, the Nematopsis cysts were recorded by Galtsoff in the small *Ostrea virginica* grown on mangrove roots in Biscayne Bay, south of Miami.

PACIFIC COAST

So far, Nematopsis spores were not found in the Olympia oysters (*Ostrea lurida*), or in the Japanese oysters (*Ostrea gigas*) which were examined by Galtsoff on various occasions. In view of the fact that in Europe it occurs in various pelecypodes it is reasonable to infer that the parasite has not yet established itself in the bays of the west coast of the United State.

During the investigation conducted recently by Galtsoff (1950) in the Gulf of Panama, large numbers of oysters, *Ostrea mexicana*, were examined and found to be free from Nematopsis. One specimen of *O. chilensis* from Garachine Bay, on the east coast of the Gulf of Panama was found, however, to be slightly infected with Nematopsis.

CONCLUSIONS

Detailed data on the occurrence of Nematopsis in oyster producing bottoms in Chesapeake Bay, and scattered observations in other waters show widespread distribution of this parasite along the Atlantic and Gulf Coasts. The majority of the bars in Chesapeake Bay were affected only

TABLE 6. INTENSITY OF NEMATOPSIS INFECTION, PERCENTAGE OF INFECTED OYSTERS, SALINITY OF WATER, CHARACTER OF BOTTOM AND CONDITIONS OF MEAT OF OYSTERS IN CHESAPEAKE BAY AND ITS TRIBUTARIES, 1946-1947.

(Intensity of infection is expressed by mean number of cysts per square centimeter of mantle.)

Location	Station	Date	Number of Cysts	Percentage of Infected Oysters	Salinity at Bottom	Depth	Bottom	Meat
		1946	per square centimeter		Parts per thousand	Feet		
CHESAPEAKE BAY								
Ocean View, Square 12	A-1	Aug. 15	652	100	20.42	24	Hard sand and shell	Good
Ocean View, Square 15	A-2	15	117	100	20.21	25	Hard sand and shell	Various
Cedar Point Hollow Patuxent River	A-3	Oct. 13	326	100	....	—	....	Good
Daddie Dare	A-4	15	......	......	....	—	....	....
Sharp's Island	A-5	16	216	100	....	—	....	Good
Old Rock	A-6	16	96	100	....	—	....	Fair-good
Shell Hill	A-7	Mar. 8	73	100	11.5	12	....	Good
North Point Muds	A-8	8	539	100	11.4	18	....	Fair
Wire Ground, West River	A-9$_1$	21	8	90	8.19	24	....	Poor
Wire Ground, West River	A-9$_2$	June 25	151	100	7.00	21	sticky	Fair-poor
Gum Thicket	A-10$_1$	Mar. 4	317	100	11.72	13	....	Fair-good
	A-10$_2$	June 25	582	100	5.73	18	hard	Fair-poor
Thomas Point, South River	A-11	Mar. 4	332	100	9.56	4	....	Fair-poor
Tolley's Bar	A-12	4	524	100	9.24	20	....	Fair-poor
Broad Creek	A-13	4	18	100	11.6	11	....	Poor-fair
Love Point	A-14	Feb. 28	3	60	10.34	15	....	Very poor
Tolchester	A-15$_1$	28	12	100	7.41	14	....	Poor
	A-15$_2$	June 27	14	100	3.01	15	hard	Very poor
Southern Tea Table	A-16$_1$	Feb. 28	5	70	7.88	15	....	Very poor
	A-16$_2$	June 27	20	66	2.85	15	sticky	Poor
Flat Rock	A-17	Feb. 28	5	80	....	....	....	Very poor
CHESTER RIVER								
Blunt's Bar	B-1	June 18	93	80	7.35	16	hard sand	Fair-good
Oldfield's	B-2	18	40	80	6.69	15	hard mud	Fair-good
SEVERN RIVER								
Horn Point	C-1	July 8	259	100	4.76	14-18	hard sand	Poor-fair
Weem's Creek	C-2	8	32	100	5.11	11	soft mud	Fair-poor
Aisquith Bar	C-3	8	0	40	5.06	25	soft	Various
Eagle's Nest	C-4	8	70	100	5.10	12	hard sand	Fair-poor
EASTERN BAY								
Wade's Point	D-1	Mar. 8	26	100	11.2	16	....	Various
Wild Ground	D-2	June 18	340	100	7.65	9	grassy	Fair
Northern Mill Hill	D-3$_1$	May 13	57	100	....	....	....	Good
	D-3$_2$	June 18	292	100	7.74	12	hard sand and grass	Fair-good
HARRIS CREEK								
Church Hill	E-1	Mar. 8	11	100	11.8	13	....	Fair-good
Change Point Bar	E-2	8	38	100	11.4	16	....	Good
Turkey Nck	E-3	8	14	100	11.4	17	....	Good-fair

Piney Island	F-2	11	9	100	8.17	12	hard rock	Fair-good
Kirby Bar	F-3	11	14	70	7.05	18	hard sand	Fair-poor
PATUXENT RIVER								
Hog Point	G-1	Oct. 13	3	60	--------	----	----------------	Good
Parker Moore	G-2	13	8	100	--------	----	----------------	Good
Goodwin's Bar	G-3	1947 Jan. 31	32	100	--------	----	----------------	Good
Helln's Bar	G-4	31	53	100		----	--------	Good
NANTICOKE RIVER		1946						
Great Shoal, Wicomico River	H-1	July 15	5	90	10.14	9	hard sand	Fair-good
Middle Ground	H-2	15	2	50	10.91	10	hard sand	Poor
Wilson Shoals	H-3	15	2	80	8.13	12	soft	Very poor
Jack's Cabin	H-4	15	1	40	6.30	9	hard sand	Fair-Poor
POTOMAC RIVER								
Herring Run	I-1	July 23	5	80	7.93	22	hard	Fair-poor
Ragged Point	I-2	23	1	50	7.67	12	hard shell	Fair
Kingcopsico Point	I-3	23	11	70	7.40	15	soft snd and mud	Fair
Heron Island	I-4	23	2	50	7.67	20	hard	Poor
Sheepshead	I-5	23	4	90	6.64	12	hard	Fair-good
Old Farms	I-6	23	----	----	6.37	25	hard shell	Fair-poor
Cobb Point	I-7	23	1	40	6.65	15	hard	Various
Swan Point	I-8	23	----	----	5.28	15	hard rock	Fair-good
Lower Cedar Point	I-9	23	..	----	5.06	12	hard rock	Fair-good
POCOMOKE SOUND								
Buoy Rock	J-1	Sept. 5	106	100	16.65	8	hard	Fair-poor
RAPPAHANNOCK RIVER								
Sting Ray Point	K-1	Aug. 30	213	100	13.95	27	----------------	Fair-good
Tin Cup	K-2	29	29	100	13.45	21	hard shell	Good-fair
Drummond Rock	K-3	29	42	100	13.45	18	hard shell	Fair
Corvan Hall	K-4	29	1	40	12.92	12-15	cinder	Good-fair
Piney Island	K-5	29	116	100	12.12	10	hard	Fair-good
Farnham's Creek	K-6	29	67	100	11.06	14	sticky	Fair-poor
NASSAWADOX CREEK								
Bayford	L-1	Sept. 5	738	100	17.72	6	sticky mud	Poor-fair
MOBJACK BAY								
Near Pultz's Bar	M-1	Sept. 9	342	100	19.20	21	soft mud	Various
YORK RIVER								
Can 3, Poquoson River	N-1	May 22	56	90	--------	----	----------------	Fair-good
Tue Marshes	N-2	Aug. 21	380	100	19.84	18	medium	Good-fair
Wormley Bar	N-3	21	22	60	19.04	13	stiff mud and sand	Good
Page's Rock	N-4	21	112	100	18.30	9-10	very hard and rocky	Fair-good
Purtan Bay Rock	N-5	21	2118	100	16.08	9-14-19 (slope)	soft	Poor
Bell Rock	N-6	21	205	100	12.64	18-25	hard sand	Fair-poor
JAMES RIVER								
Brown Shoal	O-1	Aug. 8	2210	100	15.37	12	soft mud	Various
White Shoal	O-2	8	2704	100	14.85	15	soft mud	Fair-good
Wreck Rock Shoal	O-3	8	3546	100	14.05	15.5	hard mud	Poor-fair
Point of Shoals	O-4	8	94	100	8.54	8	shells and mud	Poor
Horeshead	O-5	8	66	100	4.96	6	rocky	Fair-good

slightly; the beds in the James and York Rivers were heavily infected, and heavy infection was found in several bodies of water in Alabama, Louisiana, and Texas. Neither the distribution of the parasite nor the intensity of the infection were found to follow definite patterns which could be correlated with ecological factors.

Poor quality of oyster meats did not always correspond to intensity of infection. It is true that in cases of heavy infection (Texas, Alabama) the oysters were rather poor, but non-infected specimens obtained at the same time and from the same localities were equally bad. Improvement of the meat of infected oysters after being transplanted to better grounds made it quite clear that the quality of oyster depends primarily on its environment.

Microscopic examination of the infected oysters failed to reveal any inflammatory processes or other pathological reactions of tissues to the presence of spores. The latter appear to be well encapsulated and inactive. Poor quality of meat occasionally found in very heavily infected oysters may not be the result of an infection, but very likely the reverse is true, i.e., that poor oysters, having less resistance, are more readily infected by Nematopsis than good oysters.

Although Nematopsis is frequently found in dead and dying oysters, evidence so far obtained does not support the view that the parasite is responsible for the extensive oyster mortalities occurring on our coasts.

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(1) No unusual mortality was observed

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CULTURING PHYTOPLANKTON ON A LARGE SCALE

Several years ago it became increasingly evident that to carry on our research program the laboratory had to be provided with a large, dependable supply of plankton. Plankton wa needed to feed clams, oysters and other mol lusks, as well as their larvae.

Because of the scope and character of our work we often needed as much as 100 gallons of plankton per day. It was impractical and virtually impossible to grow such large quantities in glass flasks using the commonly accepted laboratory technique and employing culture media based on rigidly devised formulae, such as Miguel's. Fortunately, it was found that by adding some complete commercial fertilizers to sea water a rapid growth of phytoplankton could be induced and later maintained in heavy concentrations. Of the numerous fertilizing mixtures tried fertilizers 5–3–5 and 6–3–6, both used by tobacco growers, gave the best results (Loosanoff and Engle 1942). The formulae indicate the ratio of nitrogen, phosphorus and potassium. These fertilizers were mixed in a ratio of about one part fertilizer to one thousand parts water giving, as a rule, incomparably better results than those obtained with the standard chemical formulae prescribed for cultivation of plankton.

Using the fertilizers extremely rich cultures of Chlorella, Nitzschia, Prorocentrum, and many other plankton forms were grown on a mass scale at Milford Laboratory. A large, 3,000-gallon, oval tank was usually used as the container, but on several occasions the cultures were grown in the outdoor concrete tanks, each having a capacity of approximately 10,000 gallons. Obviously, because of the large quantities of plankton grown it is impossible to keep the cultures bacteria-free, or even single-specied. Nevertheless, it is comparatively easy to grow mass cultures composed of practically one species.

Our method of providing the laboratory with a dependable source of supply of large quantities of plankton worked very well in summer. However, with the onset of cold weather the culture in the outdoor tanks became poorer and eventually the tanks had to be emptied to avoid complete freezing. This was not especially inconvenient because at about the same time of the year the water in Milford Harbor, which was pumped in to supply the laboratory needs, became so cold that the mollusks began to hibernate, and could not be used in experimental work until the increase in temperature the next spring.

The situation was radically changed when Milford Laboratory was provided with warm running sea water during the cold season (Loosanoff 1949). Because of this innovation it became possible to conduct throughout late fall, winter and spring many experiments which formerly had to be confined to the summer period only. The opportunity was especially widely utilized in conditioning to ripeness oysters, quahogs, soft clams, mussels, and other bivalves, from which normal spawn could be obtained when needed for the experiments (Loosanoff and Davis 1950).

The initiation of extensive winter activities again presented the problem of having on hand a sufficient supply of plankton food. Naturally, it was impossible to grow the culture in the open tank outside because it would freeze on

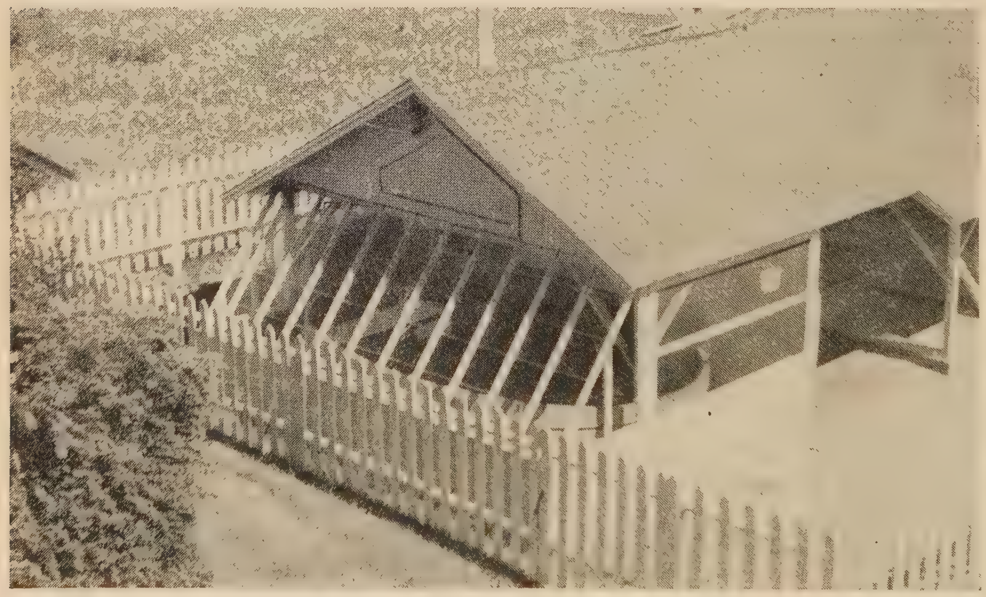

FIG. 1. Glass enclosure of plankton greenhouse. U. S. Shellfish Laboratory, Milford, Connecticut.

cold days. The problem was solved by designing and constructing a special enclosure resembling in its main features a regular greenhouse used for cultivation of plants in winter (Fig. 1). A shallow wooden tank of approximately 3,000-gallon capacity occupied the center of the enclosure, the walls of which were made of special greenhouse glass that permitted penetration of the ultra-violet rays needed for growth of phytoplankton. To maintain the culture at the desired temperature an automatic oil stove was installed in the house. Using this stove it was possible to keep the temperature of the culture at about 15.0° C. even on the coldest days of the winter. To provide the additional light needed during the period of the year when the days are short and the amount of light limited, a large fluorescent light fixture was suspended over the culture tank.

Because carrying buckets of culture from the plankton greenhouse to the main laboratory building is laborious and inconvenient, a provision is made to pump the culture directly from the tank to a central basin in the laboratory. From it the plankton is distributed by gravity, through a system of hoses and pipes, to various reservoirs from which it is slowly added at the desired rates to the flowing sea water.

When some of the culture from the tank is used the loss in volume is compensated by pumping in the same quantity of new sea water. From time to time some fertilizer is added to the culture. It was found that by using our method it is possible to remove daily from the tank about 1/20 of its volume and, yet, to allow the plankton population to remain at the same level or even to show a steady increase.

Under the conditions described the culture has been doing very well for the past several years. Its density is regularly determined by using a Fuchs-Rosenthal counting chamber, commonly used for counting erythrocytes and leucocytes. The density is easily maintained between 25 and 30 million cells per cc. of *Chlorella sp.* and on some occasions a population of approximately 45 million cells per cc. was reached. In general, the culture requires very little care. Once started it may be maintained a long time without emptying and washing the tank. Once the same culture was carried on for about 18 months and was still good at the end of this period, maintaining a population of approximately 35 million cells of Chlorella per cc.

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DELAYING SPAWNING OF LAMELLIBRANCHS BY LOW TEMPERATURE

BY

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ABSTRACT

Spawning of oysters (*Crassostrea virginica*) and clams (*Venus mercenaria*) was delayed by transferring ripe or nearly ripe animals from Long Island Sound to the cold waters of Boothbay Harbor, Maine, where the temperature, although high enough to permit gametogenesis, was too low to induce spawning. With *C. virginica*, spawning could be postponed until six or eight weeks after the Long Island Sound population was completely spent, while *V. mercenaria* held over healthy summer spawn throughout the fall and winter and into the following spring. By similar means, laboratory workers can be provided with ripe animals during the fall when none are normally available in their own locality.

Until recently the eggs and larvae of lamellibranchs, such as oysters and clams, were available only during their normal spawning period. In our waters this period is relatively short, usually from about 2½ to 3 months. However, several years ago a method was developed to induce oysters to develop gametes and to discharge spawn in winter (Loosanoff, 1945). Later the same method, in somewhat modified form, was successfully applied to other mollusks (Loosanoff and Davis, 1950).

The method merely consists of a gradual increase in the temperature of the water from the low level prevailing in winter over the mollusk beds to that at which they spawn in summer. Using this simple method, *Crassostrea virginica*, *C. gigas*, *Ostrea lurida*, *O. edulis* (the European oyster), *Venus mercenaria*, *Mya arenaria*, *Mactra solidissima*, *Anomia aculeata*, *Ensis directus*, *Petricola pholadiformis*, and several other lamellibranchs have been conditioned at our laboratory to develop and discharge normal gametes throughout the winter and spring.

In the same way we have also succeeded in ripening the common starfish of Long Island Sound, *Asterias forbesi.* The gastropod oyster drill, *Urosalpinx cinerea*, was also conditioned to deposit egg-cases in the middle of winter. We think that the method is well suited to ripen for spawning many other invertebrates, including annelids, the eggs and larvae of which were often found when we spawned oysters in winter.

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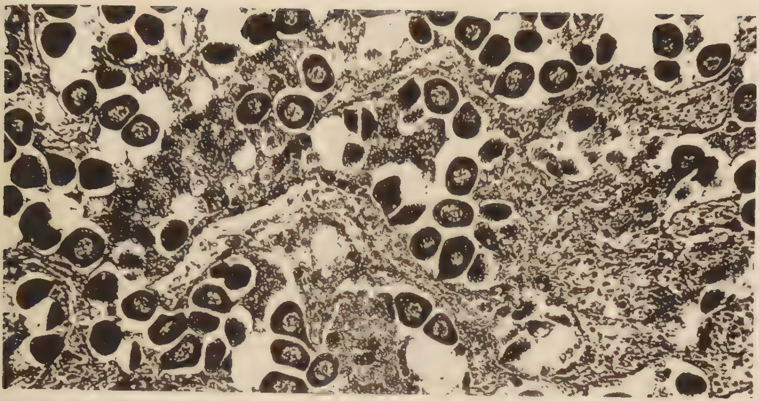
Conditioning lamellibranchs for spawning in late fall and winter is possible only after they recover from the natural summer spawning. Recovery consists of an accumulation of reserve materials, such as glycogen. In our waters that stage may not be reached by some lamellibranchs until the end of October. Thus, since these lamellibranchs become spent some time during late August or early September, and since they cannot be conditioned for fall and winter spawning until November, their ripe sex products are not available during the intervening period. To solve the problem of providing the laboratory with mollusks in spawning condition during this period, the following experiments were made.

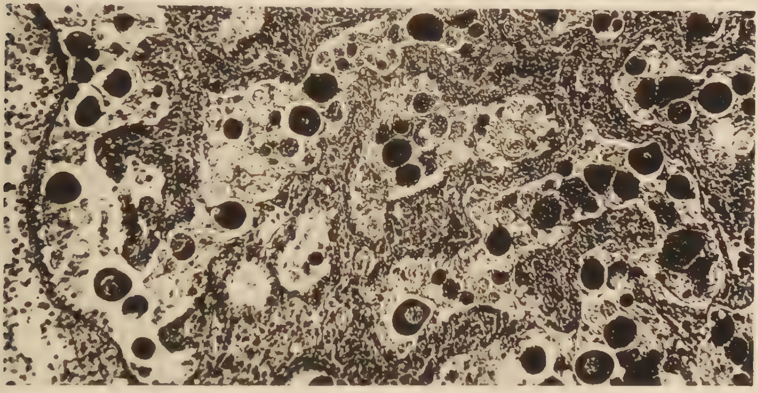
At the end of May 1950, several bushels of adult oysters (*C. virginica*) and clams (*V. mercenaria*) from Long Island Sound were planted in the waters of Boothbay Harbor, Maine. Since the water of Boothbay Harbor in summer is about 5–8° C. cooler than that of Long Island Sound, we reasoned that the temperature of the Boothbay Harbor water, while not arresting the development of the gametes of our mollusks, would, nevertheless, remain low enough to prevent the mollusks from spawning. Thus, by the time the oyster and clam populations of Long Island Sound were completely spawned out, or nearly so, those kept in the Maine water would still retain sperm or eggs and could, therefore, be induced to spawn when needed.

Oysters and clams of the first group, brought from Maine on September 7, 1950, were ripe with extremely thick gonads and were easily induced to spawn with a discharge of large quantities of eggs and sperm.

The second group was brought to Milford on October 3 nearly a month later. These oysters were ripe also, but unlike the first ones, only some of them could be induced to spawn while others already showed evidence of resorption of the unspawned ova (Fig. 1). The clams, on the other hand, showed no evidence of spawning or of resorption of gonadal material. They responded quickly to spawning stimulation, which consisted of a rapid increase in the water temperature to about 32.0° C. and the addition of egg or sperm suspension; large quantities of normal spawn were discharged.

The third group was brought from Maine on October 24, about three weeks later than the second batch. At that time the temperature of the water at Boothbay Harbor was approximately 9.0° C. After being brought to Milford, the mollusks were placed in the large tide-filled outdoor concrete tank where the temperature was about 10.0° C. An attempt to spawn the oysters of this group on October 26 was unsuccessful. Of the 40 oysters used, only one male responded, and even this was only a feeble spawning, consisting of a discharge of sperm with considerable quantities of amorphous matter and blood





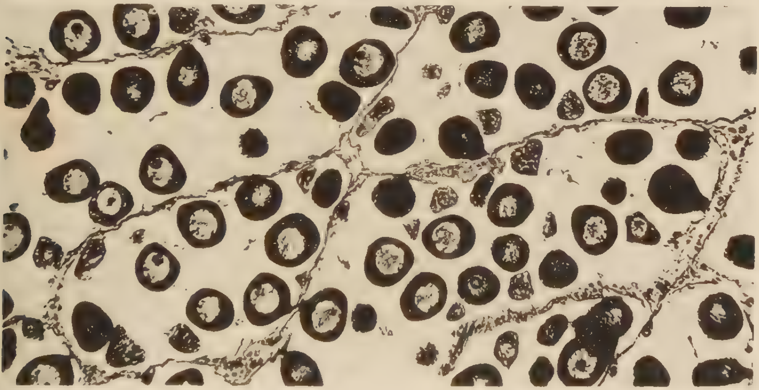


Figure 1. Gonad of female oyster in early stages of resorption. X112 Figure 2. Gonad of female oyster in advanced stages of resorption. Notice many cytolized eggs. X112 Figure 3. Section of gonad of experimental clam, *Venus mercenaria*, preserved in December. X112

cells. Examination of the remaining 39 oysters showed that resorption was already in progress in the majority of them and was well advanced in some (Fig. 2).

The clams that were brought to Milford on October 24 were distinctly different from the oysters in both condition and behavior. There was no evidence of resorption of gonadal material, and two days after arrival every one of the 15 clams responded to spawning stimuli. The discharged eggs developed into larvae which were cultured to metamorphosis.

Because the oysters were resorbing their gonads by the end of October, no further attempts were made to spawn them. However, systematic observations on the clams were continued, since their condition and their physiological behavior were different. The source of supply for these observations was the large group of clams that was brought from Maine on October 24, 1950; these were kept in our outdoor tank. A sample consisting of 10 individuals was taken from the tank on November 7 and again on November 15. All of the clams spawned in response to stimulation. In the latter case the clams came directly from water of only 8.1° C. The eggs obtained from both spawnings developed normally and the larvae were again cultured to the setting stage.

As the season progressed, groups of clams were brought into the laboratory from the outdoor tank at approximately biweekly intervals to ascertain whether they still could be induced to spawn and produce viable zygotes. It was noticed, however, that the clams did not respond to spawning stimuli as readily as they did earlier in the season. Sometimes they had to be kept at high temperatures for 10 or 12 hours before responding. Yet, histological examination of specimens killed and preserved immediately upon their removal from the tank showed that their gonads contained normal eggs (Fig. 3). Apparently the delay in the spawning response was due to keeping the clams in the tank at a low temperature, which was down to 6.0° C. by the beginning of December. From then on, however, the clams were brought to the laboratory and were kept there for a day or two in running water of approximately 20.0° C. before being subjected to spawning stimuli. As a rule the clams responded favorably to such treatment and, upon stimulation, discharged large quantities of spawn.

The last group of clams was induced to spawn on April 9, 1951; the larvae received from this spawning were grown to metamorphosis. Unfortunately, the sample of April 9 exhausted our supply and observations had to be discontinued.

In general, the experiments showed that it is possible to delay spawning of ripe or nearly ripe mollusks by keeping them at a comparatively low temperature. In oysters it can be delayed as late as mid-October. In other words, under natural conditions most of the oysters in our waters would be spent in August, but by using this method we can delay spawning for 6 or 8 weeks, i. e., until the time of year when the oysters living in Long Island Sound will be ready to be conditioned for winter spawning. Spawning of *V. mercenaria* can be delayed even longer than that of oysters. Thus, using a combination of our two methods, one of conditioning for winter spawning (Loosanoff and Davis, 1950) and the other of delaying spawning in late summer and fall by low temperature, it is possible now to have ripe lamellibranchs available throughout the year.

Somewhat similar results in the delay of spawning were achieved by taking ripe mollusks from Long Island Sound in midsummer and by keeping them in the laboratory in an insulated container through which mechanically-cooled sea water was flowing. Basically the principle is the same as keeping them in the cool water of Maine. However, only a small number could be conveniently kept in the laboratory under semirefrigerated conditions. Furthermore, a rapid increase in temperature due to failure of the mechanical devices always caused major and complete spawning, thus rendering the whole group useless.

Although observations on the fate of the unspawned ova and sperm of clams and oysters are not the subject of this article, it should be mentioned here that the ability of the clams to carry undischarged spawn far into the winter, without undergoing such cytological changes that would make the gametes unviable, is of extreme biological importance and interest. It is even more significant that the retention of healthy spawn through late winter and spring occurred although the clams were exposed for several months to temperatures ranging between 0 and 6° C.

Perhaps this ability of the clam, unlike that of the oyster, which resorbs its gonads early in the fall, can be explained by the general pattern of its seasonal gonadal changes (Loosanoff, 1937). According to this pattern the production of a new crop of eggs in *Venus mercenaria* begins soon after spawning, and the chief growing period of young ovocytes is in autumn during October and November. By the onset of winter the gonads of female clams usually present a virtually mature appearance. The cells developed in autumn remain in the clam gonads throughout the winter without undergoing any degenerative processes. Nevertheless, regardless of this consideration, we should not underestimate the biological significance of the observation that normal eggs and spermatozoa which were discharged by the clams on April 9, 1951 were those which were formed some time in October or November of 1949, i. e., almost two years ago.

We are deeply indebted to our colleagues, John B. Glud and Walter R. Welsch of the U. S. Fish and Wildlife Service biological laboratory at Boothbay Harbor, Maine, whose help and friendly cooperation enabled us to carry on this study, to Charles A. Nomejko for preparing the photographs for this article, and to William S. Miller for his help in taking the mollusks to Boothbay Harbor.

SUMMARY

1. It was possible to delay spawning of clams and oysters for considerable periods by keeping them in water, the temperature of which was high enough to permit gametogenesis but too low to induce spawning.

2. While the oyster, *C. virginica*, resorbs unspawned gonads in late fall, the clam, *V. mercenaria*, carries undischarged eggs or spermatozoa through the winter and even into spring; the latter may be induced to spawn during this time, discharging viable gametes which develop into normal larvae.

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GROWTH AND SETTING OF LARVAE OF *VENUS MERCENARIA* IN RELATION TO TEMPERATURE

By

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ABSTRACT

Larvae of the hard shell clam, *Venus mercenaria*, were grown to metamorphosis at constant temperatures of 30.0, 27.0, 24.0, 21.0 and 18.0° C ± 1.0° C. The rate of growth of the larvae was generally, but not always, more rapid at high than at low temperatures. Within this range small differences in temperature, such as 1.0 or 2.0°, were not extremely important in affecting the rate of growth. The average time needed by larvae to reach a certain size or to grow to metamorphosis at different temperatures is given. Larvae obtained from the same sources and grown under identical conditions often showed considerable individual variations in the rate of growth and in the time needed to reach the stage of metamorphosis. Fertilized eggs placed in water of 15.0 or 33.0° C ± 1.0° C showed abnormal development and heavy mortality, few ever reaching veliger stage. Some food requirements of the larvae are discussed.

INTRODUCTION

At some time or other almost every student of ecology or physiology of larvae of lamellibranch mollusks has commented that temperature is the factor influencing the duration of their pelagic life. Unfortunately, most of these comments were usually too brief and incomplete. Others, even if lengthy, lacked supporting data to be of much value in analyzing the relationship between temperature and growth of larvae.

Since a review of the literature devoted to the effects of temperature upon larvae of lamellibranchs has recently been offered by Thorson (1946) and Baughman (1947), there is no need to repeat it here. We shall merely mention a few articles that have a close relation to our studies. Nelson (1908) stated that within the temperature range from 24.0 to 27.0° C the American oyster, *Ostrea virginica*, has a free-swimming period of only one week. At 23.0° C, however, this period is extended to 13 days, and at 20.0° C to 17 days. Medcof (1939) concluded that oyster larvae require approximately 24, 26 and 30 days to reach maturity at a constant temperature of 21.0, 20.0 and 19.0° C respectively. According to Korringa (1941), *Ostrea edulis* of Holland has a pelagic life of six days at a temperature of 22.0–23.0° C, 9 to 10 days at 18.0–21.0° C, and 13 to 14 days at 16.0–17.0° C. Belding (1912) thought that the free-swimming period of larvae of *Venus*

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mercenaria is 10 to 12 days at a temperature of approximately 22.0° C, but somewhat longer at lower temperatures.

Thus, the general opinion is that temperature may hasten or prolong the larval period. Furthermore, it is believed that a difference of only one degree, between 19.0 and 20.0° C, may prolong the swimming period of larvae by as much as four days (Medcof, 1939). However, the accuracy of the day-degree relationships offered may be questioned, since the number of days needed by larvae of different lamellibranchs to reach the setting stage at certain temperatures was decided largely upon the basis of field observations, where it is always difficult and usually impossible to evaluate the relative importance of other factors such as salinity, pH, food, etc. It is thought, therefore, that such relationships can be best determined by laboratory experiments where most of the factors can be rigidly controlled. This paper offers a description of studies devised to determine the rate of growth, length of free-swimming period, and other aspects of the behavior of larvae of the hard shell clam, *Venus mercenaria* L., grown at different but constant temperatures.

We wish to express our appreciation to our colleague, John H. Peterson, for tabulating some of the data on which this article is based.

METHODS

The larvae were grown at constant temperatures of 33.0, 30.0, 27.0, 24.0, 21.0, 18.0 and 15.0° C ± 1.0° C. They were kept in earthenware crocks of 20-liter capacity. These crocks, which were covered with black painted glass to exclude the light, were immersed in large containers through which water of a constant temperature was running continuously, thus maintaining a constant temperature within the crocks. Duplicate crocks were used for each temperature. The crocks were filled with sea water filtered through a thick layer of cotton.

The largest part of this work was done during the winter and early spring, the time which we found most convenient to control the temperature of the water (Loosanoff, 1949). Sperm and eggs were taken from clams which were conditioned to spawn in winter (Loosanoff and Davis, 1950). To avoid the shock of temperature changes, the fertilized eggs were gradually brought up or lowered to the temperatures in which they were to be cultured. Usually one million eggs were introduced in each crock, making the initial concentration of 50,000 eggs per liter of water.

The cultures were changed every two days by using the method already described (Loosanoff and Davis, 1950). After the water had been changed, the larvae were fed a mixture of *Chlorella* sp. and a purple sulfur bacteria, *Chromatium perty*, creating in the culture crocks a concentration of approximately 300,000 cells of *Chlorella* and 400,000 cells of sulfur bacteria per cc of water. It is interesting that the sulfur bacteria, which were rejected as food by the oysters (Loosanoff, 1949a), were readily taken in and apparently assimilated by the larvae of *V. mercenaria.*

Altogether four major experiments were conducted. In the first, no larvae were measured until the fourth day. In the subsequent experiments, however, larvae from all the cultures were measured at the end of the second day after fertilization. In one 30.0° C culture, measurements were made as soon as the larvae reached the straight hinge stage, which occurred in less than 24 hours.

From each crock 50 larvae were taken for measurement on each occasion. However, because the cultures were run in duplicate, the number of larvae taken as a sample for each temperature group was actually 100. As a rule, in all experiments the duplicate samples showed extremely close agreement.

Measurements of the larvae were made in the usual manner, using a Sedgwick-Rafter cell to hold the larvae. Since each of the small divisions of our ocular micrometer was equal to seven microns, most of our figures were based on these intervals. In some cases, when the necessity arose to determine the measurements more precisely, the larvae were measured under high-dry power where each division of the ocular micrometer was equal to only 1.7 microns. In general, however, it was found impractical to be confined to such accurate measurements, because the variation in the measurements of the larvae depended to some extent upon the position in which the larva was lying on the slide. This was especially true of the older larvae, the shapes of which were more rounded than those of the relatively flat young ones.

RESULTS

We would like to mention here that this discussion is based on the results of experiments in which the clams of only one geographic area—Long Island Sound—were used to furnish the spawn. This point is emphasized because it is considered possible that within the general population of *Venus mercenaria*, which extends from the Gulf of St. Lawrence to Texas, there are local races of clams whose physiological requirements may differ from those of Long Island Sound clams. That such physiologically-different races of the same genus may exist among lamellibranchs has been shown recently for the common American oyster, *Ostrea virginica* Gmelin (Loosanoff, unpublished manuscript).

First our discussion will be confined to the temperatures within the range of 18.0 to 30.0° C. The results observed at 15.0 and 33.0° C will be discussed later, because the development of the eggs and larvae at these temperatures was usually abnormal.

Within the range from 18.0 to 30.0° C the mortality of the eggs and then the larvae was comparatively low. It is estimated that often not less than 85% of these were carried to the stage of metamorphosis. The only exceptions were several cultures grown at 18.0° C, where somewhat fewer eggs developed into larvae of straight hinge stage. However, those that reached that stage usually lived through metamorphosis.

The larvae in all cultures behaved normally. They were usually vigorous and rapid swimmers, this condition necessitating that they be killed with formalin before measurements were taken. Their color was usually pinkish-yellow-green, characteristic of the type of food they were fed. Incidentally, our experience has shown conclusively that the color of larvae of *V. mercenaria*, as well as that of larvae of some other lamellibranchs, such as *Mya arenaria* and *Mactra solidissima*, with which we worked at different times, should not be considered as a reliable specific characteristic that may be helpful in identifying larvae. We formed this conclusion because we found that the color of the larvae may be changed at will, within an hour or so, by feeding them micro-organisms of different colors.

The data on growth of larvae at different temperatures in Experiments 1 through 4 are given in Figs. 1, 2, 3 and 4. The curves of these figures are based upon the mean length of the larval populations as determined by measurements of representative samples at two-day intervals. As already mentioned, the exception was Experiment 1, where the larvae were not measured until the end of the fourth day. In Experiment 4, which was conducted in the early summer when the water temperature was already higher than 18.0° C, no cultures were grown at that temperature. In Figs. 1, 2, 3 and 4 the curves terminate at 185 microns. This arbitrary size was taken as the terminal point of the curves because in some instances it was found that, when the mean length of the larvae in the culture was approaching 185 μ, many larvae were already metamorphosing, thus dropping out of the free-swimming population.

The metamorphosis of a larva of *V. mercenaria* into a young clam is not as sharply defined as is the metamorphosis or, as it is commonly called, setting of an oyster, at which time the larva ceases crawling entirely and cements itself to a shell or other clean object. In *V. mercenaria*, as well as in some other clams, metamorphosis is an extended process beginning with the gradual replacement of a ciliated

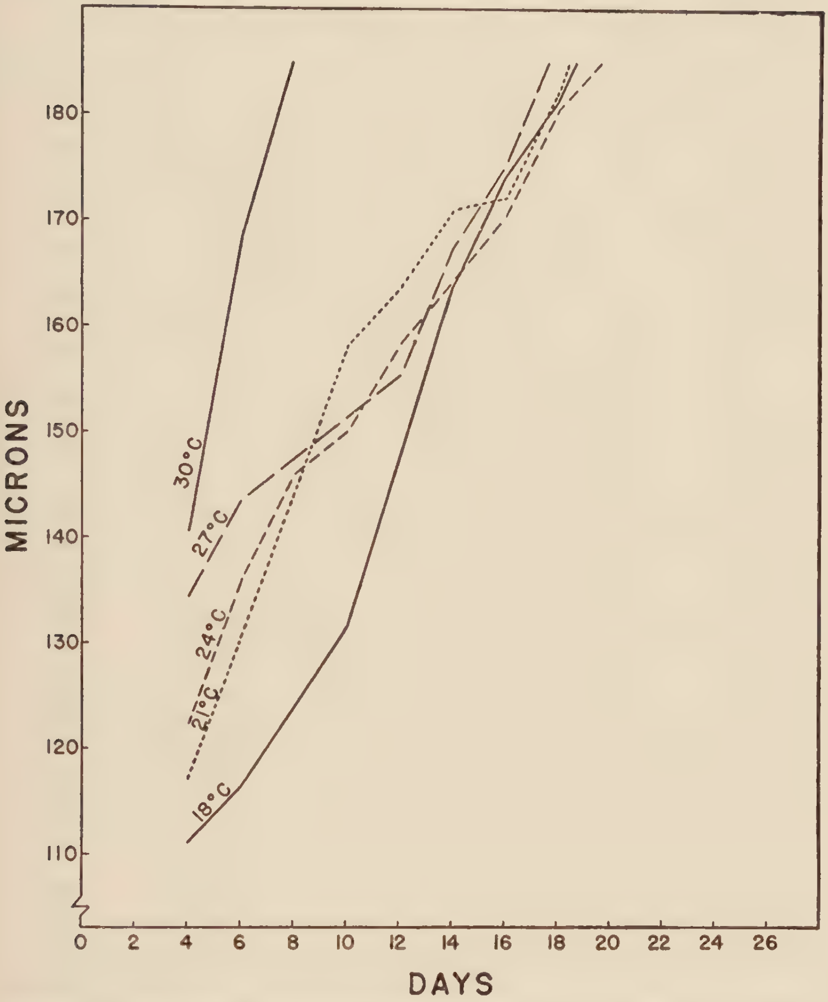

Figure 1. Mean length of larvae of different ages grown at five constant temperatures. Experiment 1.

velum with a large muscular foot and ending with the development in the foot of a functional byssal gland. This point is often difficult to establish, because many young clams, although possessing a byssus gland, do not always attach. Therefore, it may be difficult at times to distinguish a very young clam from an old ready-to-metamorphose larva.

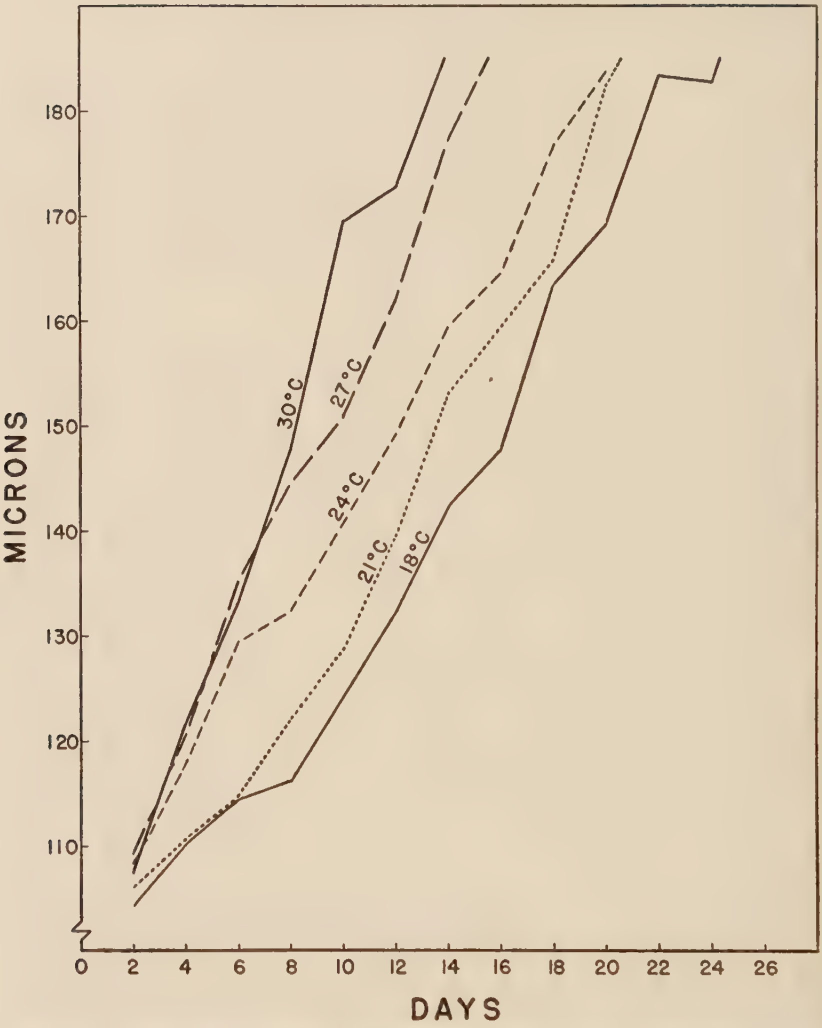

Figure 2. Mean length of larvae of different ages grown at five constant temperatures. Experiment 2.

The length at which metamorphosis took place in our cultures ranged from approximately 175 to 236 μ, occurring most commonly between 200 and 210 μ. The largest larvae did not always metamorphose first. In several cultures some comparatively small individuals of only approximately 180 μ did metamorphose, while larger

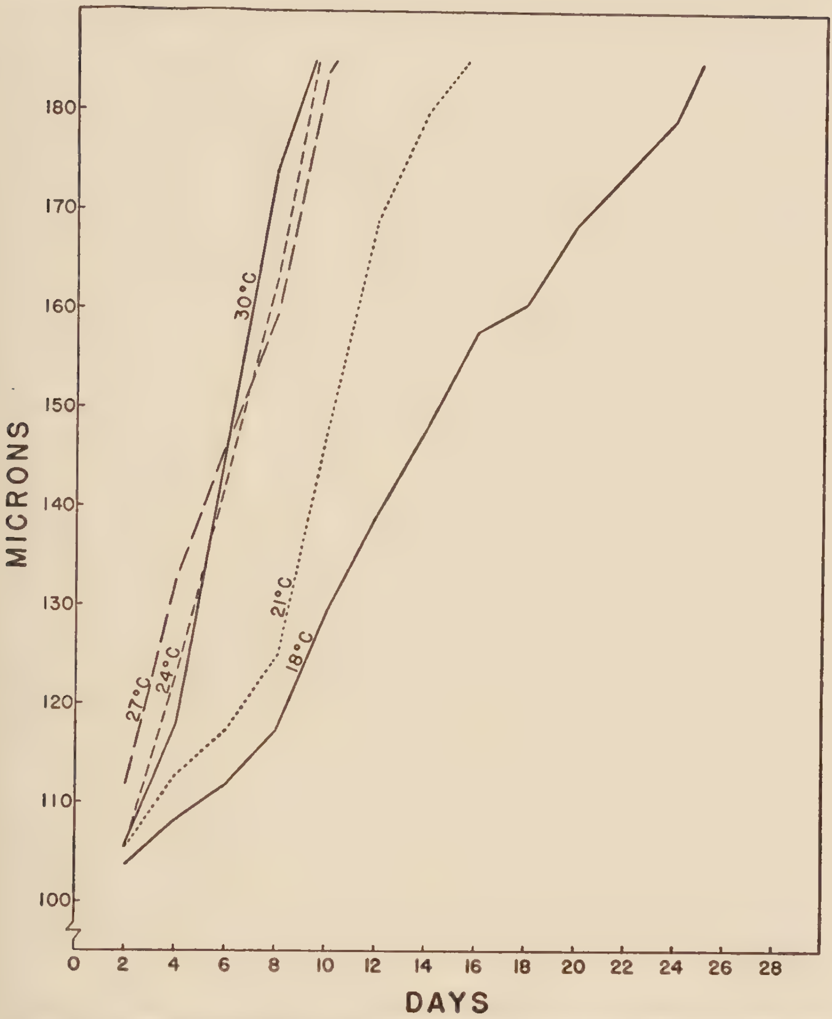

Figure 3. Mean length of larvae of different ages grown at five constant temperatures. Experiment 3.

larvae of more than 200 μ still continued swimming, at the same time displaying a powerful velum and a comparatively small foot.

In the course of these experiments we tried to determine whether larvae grown at low temperatures, such as 18.0° C, would reach a larger size before setting than larvae grown at higher temperatures. Some of the preliminary experiments did indicate a tendency of this

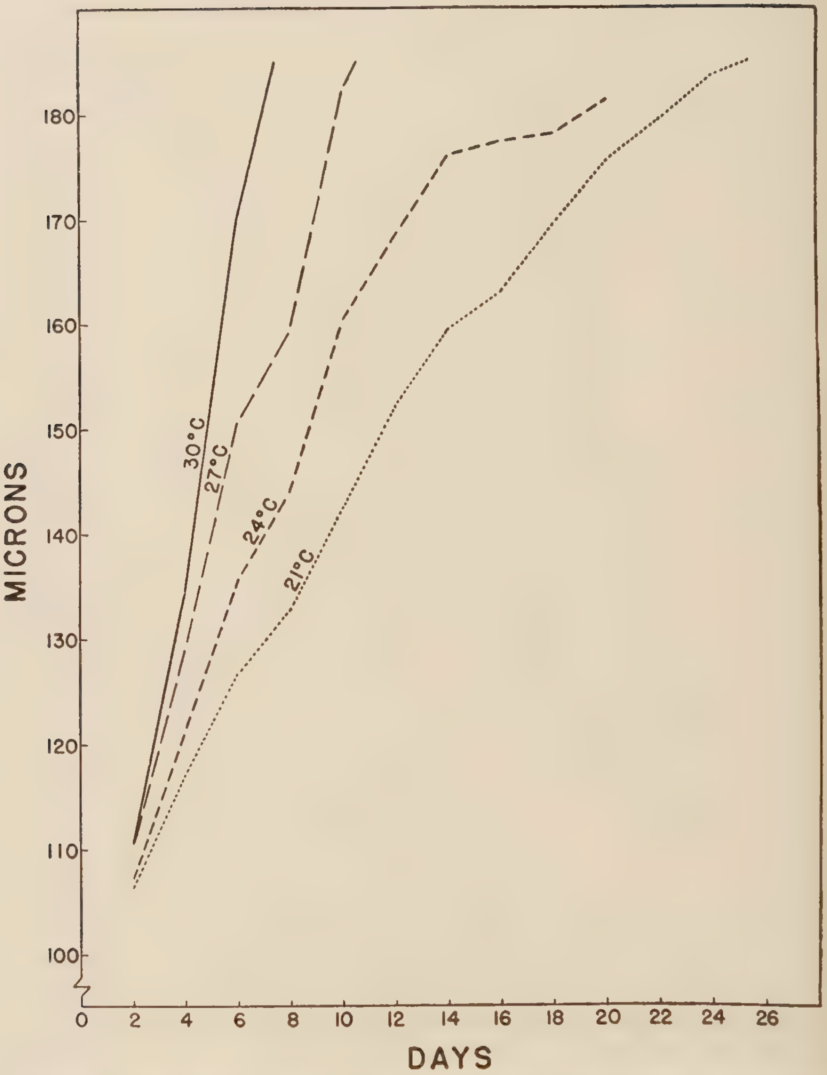

Figure 4. Mean length of larvae of different ages grown at four constant temperatures. Experiment 4.

type, but further and more extensive experiments did not support this contention.

With exception of the 30.0° C group, the results of the first experiment showed that the rates of growth of the other four temperature groups closely resemble each other, indicating that, within the temperature range of 18.0 to 27.0° C, differences in temperature do not always significantly affect the rate of growth (Fig. 1). When plotted, the data do not resemble the exponential growth curves offered by Medcof (1939) for the growth of larvae of *O. virginica.* Moreover, contrary to the findings on some other lamellibranchs (Seno, et al., 1926), the larvae kept at 30.0° C did not die but showed healthy and rapid growth, some of them reaching the setting stage during the seventh day after fertilization, i. e., considerably ahead of the cultures kept at lower temperatures.

Subsequent studies (Figs. 2, 3 and 4) showed that the results of Experiment 1 were somewhat atypical. Nevertheless, they are included here not only for comparison and discussion but partly to demonstrate the possible deviations that may occur in this type of study. Naturally, we sought for an explanation of the peculiar results observed in Experiment 1. Critical analysis of the methods and procedures used during the experiment showed that the only factors that varied from culture to culture were temperature, and possibly aeration. Other factors, such as number of larvae, quantity of food, salinity, pH, amount of light, etc., were identical in all cultures. Of course, the differences in the temperatures were the basic part of the experiment. The differences in aeration, the only factor that was not rigidly controlled, had to be properly evaluated. The following experiment was designed to evaluate the importance of such differences.

Several cultures of larvae were started under identical conditions except for the degree of aeration. Some crocks were aerated very vigorously, the water surface resembling that of boiling water in a bucket; other crocks were aerated only feebly; the third received no aeration whatsoever with exception of unavoidable splashes that occurred during a water change every second day. It was found that vigorous aeration of the cultures was unnecessary after the larvae had reached the straight hinge stage. Actually, clean and carefully attended cultures were brought to the setting stage without continuous aeration. The larvae of the unaerated cultures showed approximately the same percentage of survival, grew at the same rate and began setting at the same time as the feebly or strongly aerated cultures which, in turn, showed no significant differences. Obviously, since the differences in degree of aeration in the cultures of Experiment 1 were incomparably smaller than those of the cultures of the specially designed experiment, we may conclude that aeration was not responsible for differences in the rates of growth of larvae in the different cultures of Experiment 1.

Experiments 2, 3 and 4 showed agreement in general, the rate of growth of the larvae being more rapid at high than at low temperatures (Figs. 2, 3 and 4). However, even in these experiments certain discrepancies were noted. For example, in Experiment 2, on the sixth day, the mean length of the larvae grown at 27.0° C was somewhat greater than that of the 30.0° C group (Fig. 2). In Experiment 3, until the sixth day, the mean rate of growth of the larvae was also more rapid at 27.0° C than that at 30.0° C (Fig. 3). Furthermore, even the 24.0° C group of this experiment was, for some time, growing more rapidly than the 30.0° C group.

TABLE I. Number of Days Needed after Fertilization for the Beginning and for the Completion of Setting of Larvae at Different Temperatures in Each of Four Experiments; Range in Days between the Beginning and Completion of Setting, and the Maximum Number of Days during Which Setting May Extend in Cultures Grown at the Same Temperatures

Temp. °C	*Days*				*Range in days*	*Number of days*
	Expt. 1	*Expt. 2*	*Expt. 3*	*Expt. 4*		
18.0	16–28	24–30	19–30	—	16–30	14
21.0	14–24	20–26	17–22	18–28	14–28	14
24.0	14–22	17–22	11–14	14–22	11–22	11
27.0	14–20	13–18	9–14	10–14	9–20	11
30.0	7–12	9–16	7–14	7–12	7–16	9

To summarize the results of all four experiments, the arithmetic means of all the length measurements for each temperature at definite times were taken and the curves fitted by the method of moving averages (Fig. 5). The curves showed that growth of the larvae was more rapid at high than at low temperatures. However, the upper portions of the curve did not suggest that the distances between the terminal points of the curves significantly increased as the temperature decreased, as was shown by Medcof (1939) for oyster larvae.

At 30.0° C, setting of larvae in three experiments began as early as the seventh day after fertilization, but in one it was delayed until the ninth (Table I). The entire population of the cultures kept at this temperature metamorphosed within five to seven days after the beginning of setting (Table II). However, the range in days between the beginning and completion of setting at this temperature, as based on all four experiments, extended from the seventh to the 16th day after fertilization and covered a period of nine days (Table I).

At 18.0° C, the earliest beginning of setting was recorded 16 days after fertilization, the latest beginning 24 days after fertilization (Table I). The range in days between the beginning and completion of setting at this temperature extended from the 16th to the 30th day after fertilization, thus covering a period of 14 days. While in Experi-

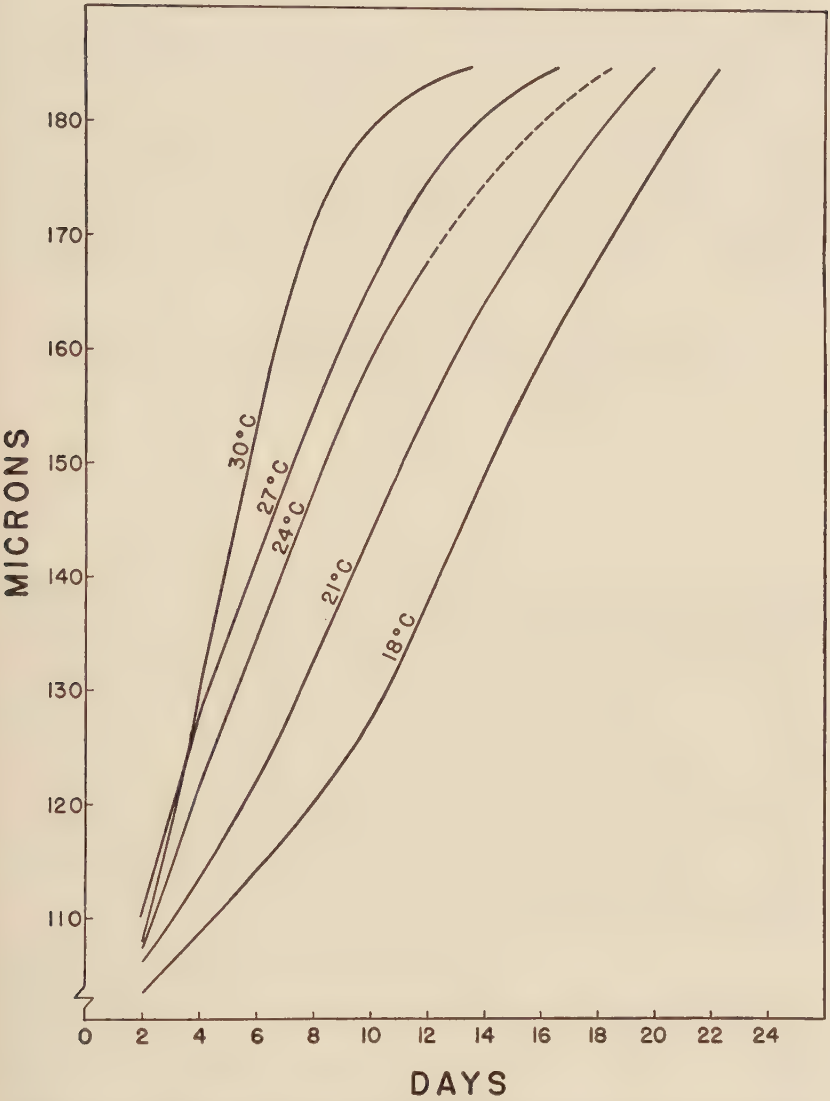

Figure 5. General trend of increase in length of larvae grown at different temperatures, as based on measurements made in four experiments.

ments 1 and 3 setting at 18.0° C continued for 12 and 11 days respectively, in Experiment 2 it was completed in only six days, thus indicating considerable variation in the behavior of a population of clam larvae, presumably kept under identical conditions.

The number of days needed after fertilization for the beginning and completion of setting of larvae at the three intermittent temperatures of 21.0, 24.0 and 28.0° C are also given in Table I. With exception of Experiment 1, where setting at three different temperatures began on the same (14th) day, in general the number of days increased with a decrease in temperature. Furthermore, even in Experiment 1, the range of setting in days increased with a decrease in temperature. Thus, for example, while setting was completed in 20 days after fertilization at 27.0° C, at 21.0° C it continued until the 24th day (Table I).

TABLE II. Number of Days Elapsing between the Beginning and the End of Setting in the Cultures Kept at Different Temperatures

Temp. °C	*Number of days*			
	Expt. 1	*Expt. 2*	*Expt. 3*	*Expt. 4*
18.0	12	6	11	—
21.0	10	6	5	10
24.0	8	5	3	8
27.0	6	5	5	4
30.0	5	7	7	5

The number of days elapsing between the beginning and the end of setting in cultures kept at different temperatures did not always follow a definite pattern. Experiment 1 was the only one in which there was a definite trend showing that the number of days needed for the completion of setting of the entire larval population decreased with an increase in temperature (Table II). In that experiment, 12 days were needed to complete the setting at 18.0° C, while at 30.0° C setting of the entire population was completed in five days. In Experiment 2, however, no such relation was found. In fact, setting was completed within a somewhat shorter period at 18.0° C than at 30.0° C. Experiments 3 and 4 also present in this respect a somewhat inconsistent picture, although Experiment 4 generally resembles the trend found in Experiment 1 (Table II).

Our studies showed that the larvae, which came from the same spawnings and which were kept in the same crocks, obviously under identical conditions, showed great variations in size. Taking as an example the data of Experiment 2, one will find that, early in the experiment, on the second day after fertilization, the range in length of larvae was comparatively small (Table III). At a temperature of 18.0° C it ranged between 93 and 107 μ, while at 30.0° C it extended from 93 to 121 μ. However, as the experiment progressed, the difference between the minimum and maximum sizes increased. Toward the end of the experiment the length range of the larvae in the 18.0° C culture extended from 150 to 221 μ and in the 30.0° C culture from 150 to 207 μ. At some intermediate temperatures, for example that of 21.0° C, the differences in the length of the larvae during the last days of the experiment were even greater, extending from 136 to 236 μ (Table III).

The differences in sizes of larvae of the same age, presumably grown under identical conditions, become even more striking if the data from all four experiments are analyzed. Considering, for the sake of convenience, the measurements of the larvae of only two temperature groups, namely 21.0 and 30.0° C, we will again see that the larvae differed in length by only a few microns at the early stage of cultivation, on the second day, whereas several days later these differences covered practically the entire larval size-range extending from small straight hinge larvae of approximately 100 μ to full grown larvae in excess of 200 μ. For example, on the eighth day the sizes of the larvae grown at 30.0° C ranged from 107 to 226 μ (Fig. 6). Similarly, for the culture kept at 21.0° C the length of the larvae measured on the 18th day ranged from 107 to 221 μ.

TABLE III. Minimum and Maximum Lengths of Larvae of *V. mercenaria* Recorded Every Second Day in Cultures of Experiment 2. Data for Each Date and Temperature Are Based on 100 Measurements

Days	*Temperature*									
	18.0° C		*21.0° C*		*24.0° C*		*27.0° C*		*30.0° C*	
	Min.	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*
2	93	107	93	114	86	114	100	121	93	121
4	100	121	100	121	100	136	100	136	100	143
6	100	143	100	129	114	150	107	164	93	164
8	100	129	107	136	121	164	114	172	107	193
10	107	143	107	157	114	164	107	186	129	207
12	107	150	114	164	114	172	114	207	121	214
14	107	164	114	179	121	186	136	214	150	207
16	114	179	121	186	121	193	129	207	—	—
18	107	200	107	193	150	193	136	214	—	—
20	121	200	136	214	129	214	—	—	—	—
22	143	207	136	221	—	—	—	—	—	—
24	129	207	136	228	—	—	—	—	—	—
26	150	221	136	236	—	—	—	—	—	—
28	150	221	—	—	—	—	—	—	—	—

Sometimes, as is shown for the temperature of 30.0° C (Fig. 6), the range of the larval sizes sharply contracted during the last days of the experiments. This happened partly because the larger individuals were rapidly setting and disappearing from the free-swimming population and partly because the undeveloped slow-growing larvae, usually defective in some respects, were dying off just as rapidly.

The data offered in Fig. 6 give only the extremes of the larval sizes without showing the prevalence of certain size-groups in the larval population. An example of such length-frequency distributions of

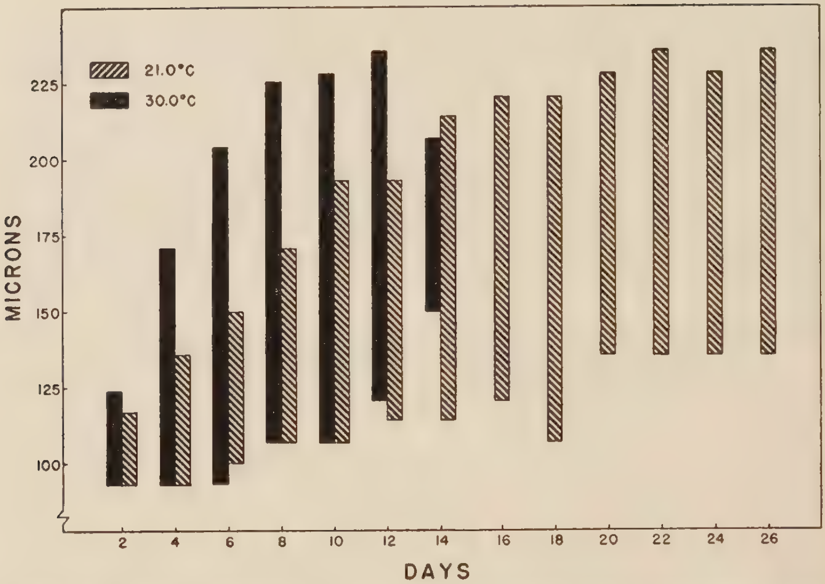

Figure 6. Extent of variations in length of larvae on different days of cultivation. Based on measurements of larvae grown at 21.0 or 30.0° C in all four experiments.

larvae is given in Fig. 7, which is based upon the measurements of the larvae grown at 18.0, 24.0 and 30.0° C in Experiment 2. The temperature selected represented the lowest, the highest, and the average of the five temperature classes. Experiment 2 was chosen as the example because it approaches most closely the mean of all four experiments. At the end of two days the length-frequency distribution of the larvae of the three cultures was relatively uniform, occupying a comparatively narrow range and showing a modal class of approximately 107 μ. Between the fourth and sixth days, however, the differences between the length-frequency distribution of the larval population of the three cultures had already become prominent. The difference was especially evident in the case of the modal classes. While for the 18.0° C group this class was 114 μ, for the 24.0 and 30.0° C groups these classes were 129 and 143 μ respectively (Fig. 7).

As the experiment progressed, the differences in length-frequency distribution of the larvae from the three cultures remained significant. In all instances the lengths of the modal classes of cultures grown at higher temperatures were greater than those at lower ones.

On the 18th day the comparison could be continued only between the 18.0 and 24.0° C cultures because the larvae in the culture of 30.0°

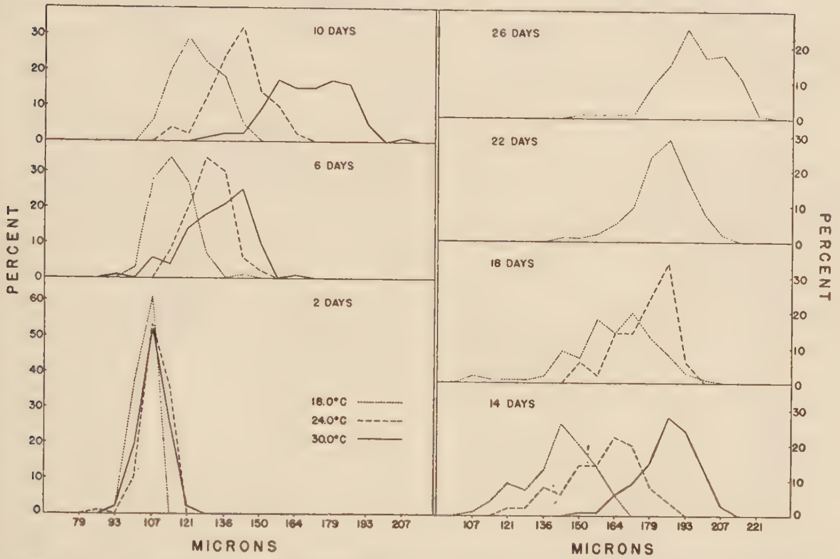

Figure 7. Length-frequency distribution (expressed in per cent) of larvae of different ages grown at temperatures of 18.0, 24.0 or 30.0° C. Experiment 2.

C had already set. For a similar reason the length-frequency distribution of the larvae after the 22nd day was available only for the 18.0° C culture.

The length-frequency distributions of larvae grown at the same temperatures but in four different experiments did not always closely resemble each other. For example, examining the length measurements of larvae grown at a temperature of 24.0° C in each of the four experiments, we found that the differences in the modal classes of the four cultures became apparent as early as the fourth day (Fig. 8). At eight days these differences became even more sharply defined. On the 12th day, while the cultures of Experiments 1 and 4 showed considerable agreement, and while the culture of Experiment 2 was not greatly different from those two, the culture of Experiment 3 definitely deviated from the others. The difference was not only in the size-range of larvae but also in the size of the modal class which measured 207 μ, as compared with 164 μ of the modal classes in the cultures of Experiments 1 and 4.

The culture of Experiment 3 set on the 14th day; therefore the comparisons made on 16 and 20 days are based only on the cultures of Experiments 1, 2 and 4 (Fig. 8). At 16 days the cultures of Experiments 1 and 4 showed close agreement, while the culture of Experiment

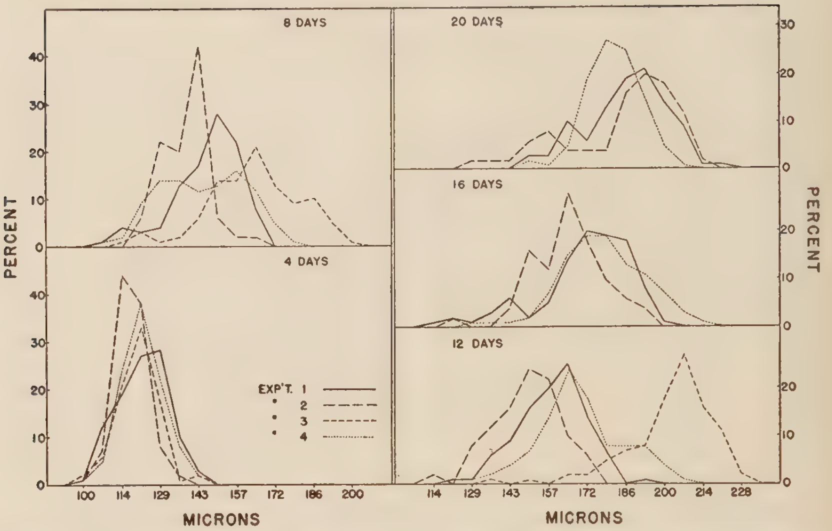

Figure 8. Length-frequency distribution (expressed in per cent) of larvae of different ages grown at a temperature of 24.0° C in the four experiments.

2 differed somewhat from the other two. However, at 20 days the agreement which existed previously between the cultures of Experiments 1 and 4 disappeared because, while the modal class of the culture of Experiment 1 showed a considerable increase, that of the culture of Experiment 4 remained practically the same. Meanwhile, the culture of Experiment 2 displayed rapid growth, thus catching up with the culture of Experiment 1.

On the basis of this comparison it may be concluded that the length-frequency distribution of the larvae grown at the same temperature in the four experiments, and otherwise kept under identical conditions, nevertheless showed considerable differences. The question naturally arises as to whether, regardless of all the precautions taken, there might have been some not-easily-identifiable differences that existed during the conduct of the four experiments which caused the lack of uniformity in the results. As far as the methods and procedures were concerned, it is certain that they were the same in all experiments. The same holds true in regard to salinity, pH, and other presumably important qualities of the water used. However, since the experiments were conducted one after another during several months rather than simultaneously, it is possible that the water used in the different experiments did differ in some respects. Even if the water were always filtered through a thick layer of cotton, thus removing most of the plankton, nevertheless minute quantities of micro-plankton could pass through the filter. It is considered possible that the differences in quantity and quality of this micro-plankton may have accounted for the differences noted in the four experiments.

This suggestion may not appear to be well founded when it is remembered that the quantity of micro-plankton that could pass through the filters would be so small that it could not add appreciably to the food supply of our dense cultures of larvae. Nevertheless, it should not be disregarded, for the material passing through the filter might have been carrying traces of some substances necessary for the normal development of the larvae. Also, it is considered possible that at different times the water itself contained certain dissolved substances which, in a manner not yet understood, affected the rate of development of bivalve larvae. These possibilities merit careful study.

We shall now refer to the results obtained in experiments in which the eggs or larvae were kept at 15.0 or 33.0° C. If recently discharged eggs were placed in water of 15.0° C within three hours after fertilization, virtually none of them would undergo normal development which would result in the formation of straight hinge larvae. Some, however, would develop into trochophore larvae, usually of abnormal appearance.

If the eggs were kept at a room temperature of about 20.0–21.0° C for three to four hours after fertilization and then placed in water of 15.0° C, a few would develop into straight hinge larvae. However, the majority of these larvae would be abnormal and would soon die.

Fertilized eggs kept at room temperature for six or nine hours before being subjected to a temperature of 15.0° C gave a greater number of individuals reaching the straight hinge larval stage, but nevertheless, the majority developing that far would be abnormal and would soon perish. However, if the eggs and the resulting larvae were kept at room temperature for two days until the straight hinge stage was well formed, after which the larvae were then placed in water of 15.0° C, many of these larvae would survive. Regardless of slow growth, it is possible that, under certain conditions, some of these larvae would reach the stage of metamorphosis.

The experiments demonstrated rather conclusively that the zygotes of *V. mercenaria* in early stages of cleavage, for normal development and survival, require a somewhat higher temperature than the zygotes or larvae in later stages.

Our results of culturing eggs and larvae of *V. mercenaria* at a relatively low temperature are in close agreement with those of Seno, et al. (1926); they found that only a few of the eggs of *Ostrea gigas* kept at about 16.0° C developed into shelled larvae, most of which would be abnormal and would soon die. At about 14.0° C, however, the segmentation of the eggs was so abnormal that none developed into straight hinge larvae.

At the other end of our temperature range, 33.0° C, an abnormal development and heavy mortality occurred if fertilized eggs were immediately transferred to water of such a high temperature. However, if the eggs and larvae that hatched were allowed to develop at room temperature for 48 hours and were then transferred to water of 33.0° C, a rapid normal development of larvae followed similar to that noticed in the cultures kept at 30.0° C. In general, these observations, as well as those made at 15.0° C, fully coincide with the view expressed many years ago by Pelseneer (1901) that young cleavage stages of molluscan eggs require a narrower temperature range than the later stages.

In the course of our experiments, many thousands of measurements were made of the length and width of the veliger larvae of different ages and sizes. Part of these data, consisting of measurements of 1,250 larvae grown at a temperature of 21.0° C in Experiments 1, 2 and 3, were used for determining the length-width relationship from early straight hinge stage to metamorphosis. This relationship is shown by the curve given in Fig. 9. The numerals through which the curve is drawn indicate the frequency of occurrence of larvae of certain lengths and widths. The character of the curve closely approaches a straight line. The data used in the construction of the curve fall into distinct modal groups with very little degree of dispersion. As already pointed out, some of the dispersion may be due to the position of the larvae on the slide during the measurement.

The size of the smallest straight hinge larvae incorporated in the curve was 86 x 64 μ, the largest 236 x 228 μ (Fig. 9). We may mention that, in addition to the 1,250 measurements used for the construction of this curve, we have the measurements of over 20,000 other larvae grown in these experiments and in many other experiments conducted since 1948. Regardless of the extremely varied ecological conditions under which these experiments were conducted, we have never found a larva more than 240 μ in length. This makes it highly improbable that the larvae of *V. mercenaria* may grow up to 448.5 μ long before metamorphosis, as reported by Stafford (1912). Furthermore, the shapes and dimensions of larvae of different sizes given by Stafford as those of *V. mercenaria*, when compared with those of larvae grown in our laboratory from the eggs of adult clams made to spawn under controlled conditions, show beyond all doubt that Stafford mistook the larvae of some other bivalves for those of *V. mercenaria.*

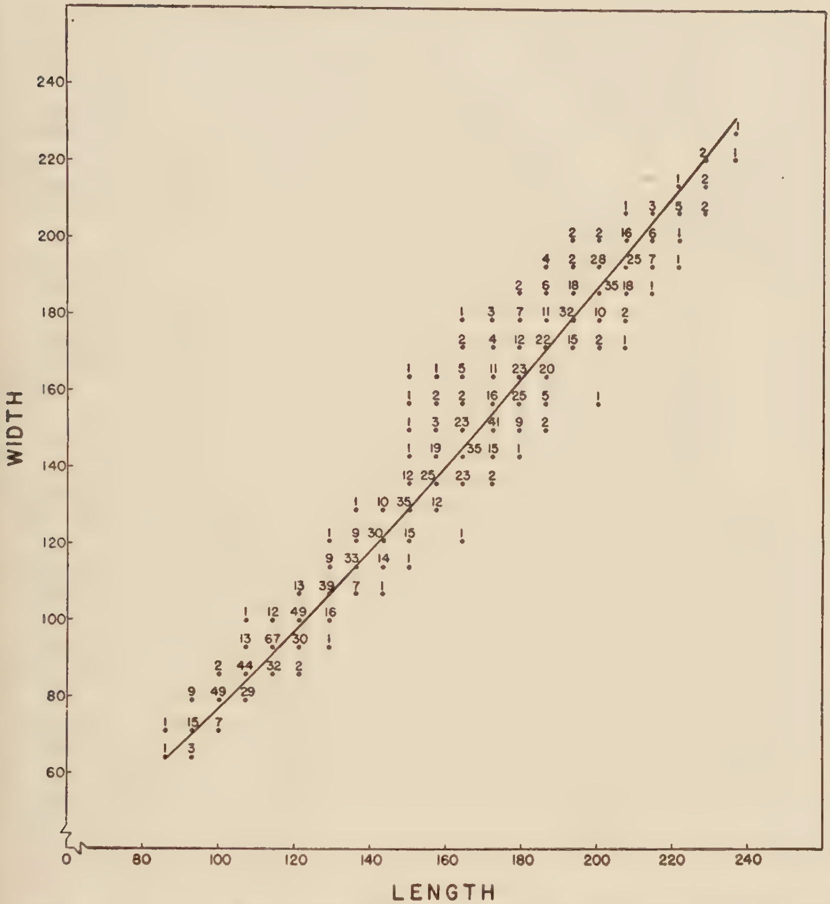

Figure 9. Length-width relationship of larvae of different sizes. Based on measurements of 1,250 larvae. Measurements in microns.

Similar remarks may be made about the conclusions of Sullivan (1948) on the size and shape of larvae of *V. mercenaria.* However, in a recent letter, Miss Sullivan clarifies the issue by writing as follows:

> It seems likely then that I have confused the larvae of *P. morrhuana* and *V. mercenaria.* This mistake is attributable to the fact that the newly settled spat of both types were very scarce in my collections. It was, furthermore, difficult to distinguish between the two types of very young spat or to identify either type with certainty.
>
> If it is the case then that my larva, *P. morrhuana,* is really *V. mercenaria,* it follows that the settling size of *Venus* larvae in Malpeque Bay corresponds reasonably well with that of *Venus* larvae in your cultures.

Incidentally our disagreement with Sullivan on the general characteristics of the larvae of *V. mercenaria* extends also to their color. Sullivan (1948) considers the color as a distinctive feature which she uses for identification of larvae of lamellibranchs. Actually, as already mentioned, we found that the color of larvae in any stage of development could be easily changed by feeding the larvae different types of food. Therefore, in nature, where the predominating species of micro-plankton may change daily, correspondingly frequent changes in the color of larvae may be expected.

In concluding, we would like to incorporate some observations which we think are of importance in studies of the growth and development of *V. mercenaria* and probably of other lamellibranch larvae as well. The first of these deals with the relative merits of detritus as food of larvae. As is generally known, during the last few years some evidence has been gathered to show that detritus was the principal food of lamellibranchs (Coe, 1948). To determine the relative importance of detritus as food of larvae of *V. mercenaria*, experiments were designed in which some cultures of larvae were fed *Chlorella*, others a mixture of *Chlorella* and sulfur bacteria, and still others were given a large quantity of detritus of one of the two types. Type 1 consisted of detritus collected from the bottom of the large tank in which plankton was grown for eight months previous to collection of the sample. During that long period, many generations of plankton died and fell on the bottom, thus creating a heavy layer of detritus which measured in excess of one-quarter of an inch. This material was filtered to remove large particles which could not be utilized and was then fed to the larval cultures. The second type of detritus was collected during the low tidal stages from the bottom of the tidal pools formed on the tidal flats of Milford Harbor. This detritus was also filtered to remove the large particles and was then fed to the larvae.

The experiments showed that there was no evidence whatsoever to support the contention that the larvae of *V. mercenaria* would grow better on detritus than on living *Chlorella* or on a mixture of living *Chlorella* and sulfur bacteria. As a rule, the cultures grown on detritus were always much inferior to those fed with *Chlorella* or its mixtures with bacteria, and the larvae usually died from starvation before they reached the stage of metamorphosis.

The second observation concerns the density of the larval population in the cultures. As already mentioned, our experiments usually began with approximately 50 eggs per cc of water. This was a much heavier concentration than that practiced or advocated by other investigators who have usually emphasized the danger of overcrowding. Our concentrations, therefore, may appear to those workers to be unrealistically dense. However, since cultures of these densities are carried at our laboratory to the stage of metamorphosis as a matter of routine, and since on many occasions we grew successfully even denser cultures, we think that in some instances the danger of overcrowding larvae of some species of lamellibranchs may not be as acute as believed. Apparently, in properly kept cultures a great majority of the larvae can survive such overcrowding, display a normal rate of growth, and reach the setting stage in the same time as larvae of much less populated cultures.

SUMMARY

1. Larvae of *V. mercenaria* were grown to metamorphosis in four experiments at the constant temperature of 30.0, 27.0, 24.0, 21.0, 18.0° C ± 1.0° C. Observations on development of eggs and growth of larvae were also performed at 33.0 and 15.0° C ± 1.0° C.

2. The size of the smallest straight hinge larvae found was 86 x 64 μ, the largest 236 x 228 μ.

3. Within the temperature range of 18.0 to 30.0° C ± 1.0° C, the rate of growth of larvae was generally, but not always, more rapid at high than at low temperatures. Small differences in temperature, such as one or two degrees, or sometimes even more, were not as important in affecting the rate of growth as was previously thought.

4. At 30.0° C, setting of larvae began in some experiments as early as the seventh day after fertilization. Setting of the entire larval population kept at this temperature was accomplished within five to seven days after its beginning.

5. At 18.0° C, the earliest beginning of setting was recorded 16 days after fertilization, the latest 24 days after fertilization. At other intermittent temperatures setting of larvae was within the bounds indicated by the two extremes.

6. The length at which metamorphosis took place ranged from approximately 175 to 236 μ, occurring most commonly between 200 and 210 μ. There was no indication that the larvae grown at lower temperatures were reaching larger size before setting than those grown at higher temperatures.

7. Larvae which came from the same source and which were kept under identical conditions showed great variation in size. In some instances the length of the larvae in an old culture ranged from about 100 μ to that of full grown larvae measuring in excess of 200 μ.

8. The length-frequency distribution of larvae grown at the same temperature but in four different experiments showed considerable variation. These variations were found in the range of larval lengths and also in the lengths of the modal classes.

9. If, immediately after fertilization, the eggs of clams were placed in water of a temperature of 15.0° C ± 1.0° C, virtually none of them would undergo normal development leading to the straight hinge stage. However, if the eggs were kept at room temperature for nine hours before they were subjected to the above temperature, some of them would develop into straight hinge larvae.

10. Eggs placed in water of 33.0° C ± 1.0° C soon after fertilization would show abnormal development and heavy mortality. However, if the zygotes were kept at room temperature of about 22.0° C for about two days after fertilization and were then transferred to the higher temperature, a rapid normal development of larvae would follow.

11. Young cleavage stages of clam eggs occur within a narrower temperature range than the later stages.

12. The color should not be considered as a distinctive feature to be used in the identification of lamellibranch larvae, because it changes easily depending on the color of the organisms eaten by the larvae.

13. No evidence was found to support the contention that organic detritus is a better food for larvae than living phytoplankton. Two types of detritus, one composed mostly of dying and decomposing plankton grown under laboratory conditions, the other collected from the bottom of tidal pools, were fed to the larvae, but such feeding caused their slow starvation and death.

14. The degree of aeration was found to be unimportant in affecting the rate of survival and rate of growth of clam larvae. Clean and carefully attended cultures could be brought to the setting stage without continuous aeration.

15. Overcrowding of larval cultures of *V. mercenaria* is not too easily achieved. As a rule, our cultures contained 50 larvae per cc of water, and several cultures, in which the concentration of larvae was more than 100 per cc of water, were grown to metamorphosis.

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EXISTENCE OF PHYSIOLOGICALLY-DIFFERENT RACES OF OYSTERS, CRASSOSTREA VIRGINICA

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Until recently it was generally accepted that the population of the American oyster, *Crassostrea virginica* Gmelin, which extends along the Atlantic Coast from Prince Edward Island, Canada to Florida, and inhabits the Gulf of Mexico, was composed of individuals of the same physiological race, or variety, showing the same physiological requirements, such as the lowest temperature at which they could begin spawning. This opinion was especially well crystalized by Nelson (1928a) in his discussion of the so-called "critical temperature for spawning of oysters," where he concluded that our oysters, as well as other lamellibranch mollusks, begin to breed at a definite temperature which is constant for the species. Somewhat later he (Nelson, 1928b) expresses this view even more precisely by stating (p. 154) that "The American oyster *Ostrea virginica* Gmelin spawns after the water temperature reaches 20° C., over all parts of its range, with no adjustment to the extremes of its distribution."

Nelson's opinion, with which most of the oyster biologists of that period agreed, prevailed uncontested until Hopkins (1931) and Loosanoff (1932) working at Galveston Bay, Texas, and James River, Va., respectively, showed that in those areas the temperature of 20.0° C. was reached far ahead of the ripening of gonads of oysters. Therefore, spawning of oysters there began at a considerably higher temperature, usually when it was near 25.0° C.

A further and, perhaps, decisive argument against the theory was raised when it was found that some of the oysters of Long Island Sound were spawning at temperatures ranging between 16.4 and 18.5° C. (Loosanoff, 1939). Thus, contrary to the established theory, it became clear that not all local groups of *C. virginica* of the range occupied by this species begin to spawn when the temperature of 20.0° C. is reached. Actually, different groups appeared to require different temperatures. This suggested that the oysters composing the different geographical groups may belong to physiologically-different races.

As far as we could establish, the first reference in the literature to the possibility of the existence of physiologically-different races within the population of the same species, *C. virginica,* was made by Loosanoff and Engle (1942). The suggestion was based upon the differences in the spawning behavior shown by the different groups of the oyster population of Long Island Sound. Several years later Loosanoff and Tommers (1948), while discussing the behavior of oysters in turbid waters, again mentioned that there appear to be physiologically-different races within the general population of *C. virginica,* some of which have developed a greater tolerance to turbidity than the oysters of Long Island Sound. Recently Stauber (1950) reviewed the rather limited material pertaining to the possibility of existence of physiologically-different races of *C. virginica,* emphasizing the need for additional research in this field. The present article is our preliminary contribution to the solution of this interesting problem.

The first steps to determine experimentally whether oysters of different geographical areas show different physiological traits were taken in the fall of 1948. Groups of young oysters, which had metamorphosed that summer, were received from Warren, Mass., Cape May, N. J., Seaside of Va., James River, Va., Pamlico Sound, N. C. and Pensacola, Fla. They were suspended in large wire trays under identical conditions in Milford Harbor. A group of Long Island Sound oysters of the same age was placed under the same conditions to serve as the control.

The chief trait to be studied was the ability of the oysters of different geographical areas to discharge spawn in our waters, where the maximum water temperatures reached during the summers are usually considerably lower than those of more southern areas. Furthermore, in Long Island Sound the period of relatively high temperatures, 20.0° and above, is of rather short duration, seldom exceeding 8 or 9 weeks (Loosanoff, 1937), while in James River, Va., from where one of our southern samples came, such temperatures may persist from about May 10 to about October 20, a period of 160 days, or about 23 weeks (Loosanoff, 1932).

Observations on the North Carolina and Florida oysters were discontinued in the spring of 1949 because 87 per cent of the first, and 97 per cent of the second group died during the preceding winter. Death was tentatively ascribed to the prolonged low temperature under which the oysters remained, but the final conclusion regarding this matter will be formed only after additional observations on the survival of southern oysters in our waters are completed.

Detailed gross and histological examinations of the remaining oysters were made on September 27, 1950. Samples, each consisting of 20 specimens, were taken from each group. By that time, all the oysters involved in these studies had spent approximately two years in Milford Harbor and, thus, were considered as having fully recovered from any detrimental conditions that might have accompanied the shipping of the oysters from their place of origin to Milford. At the time of collection the temperature of the water was already down to 16.0° C.

The results showed clearly that the gonads of the oysters of the different groups were in decidedly different conditions (Table I). All the individuals comprising the two northern groups, representing the Massachusetts and Long Island Sound populations of oysters, were completely spawned out (Fig. 1). In most instances the gonads had already passed through the stage of resorption of pycnotic cells left after spawning, and the oysters were accumulating glycogen, a normal process closely correlated in local waters with seasonal gonadal changes (Loosanoff, 1942).

In contrast with the conditions found in northern oysters, the majority of those of the three southern groups still retained all or the largest part of their spawn (Table I and Fig. 2). A few, nevertheless, possessed completely or almost completely empty gonads, although it was not determined, with absolute certainty, whether those oysters were spawned out or their gonads were resorbed after failure to spawn.

In all three southern groups many oysters had creamy, soft gonads, the thickness of which was often as much as 3.0 mm. However, in the other oysters of the same groups the consistency of the gonadal layer was, regardless of its thickness, somewhat harder than usual indicating, perhaps, that cytolysis and resorption of the undischarged material was already in progress. This condition was even more pronounced in the oysters with partially full gonads, which, as a rule, were characterized by the presence of extremely large numbers of phagocytic cells. However, even in those oysters some of the spermatozoa and eggs were normal in appearance, the spermatozoa usually becoming active if placed in a drop of water.

The average thickness of the gonadal layer of the oysters of the three groups ranged from 1.2 to 2.3 mm., being the thickest in the James River, Va. lot which was the most southern group (Table I).

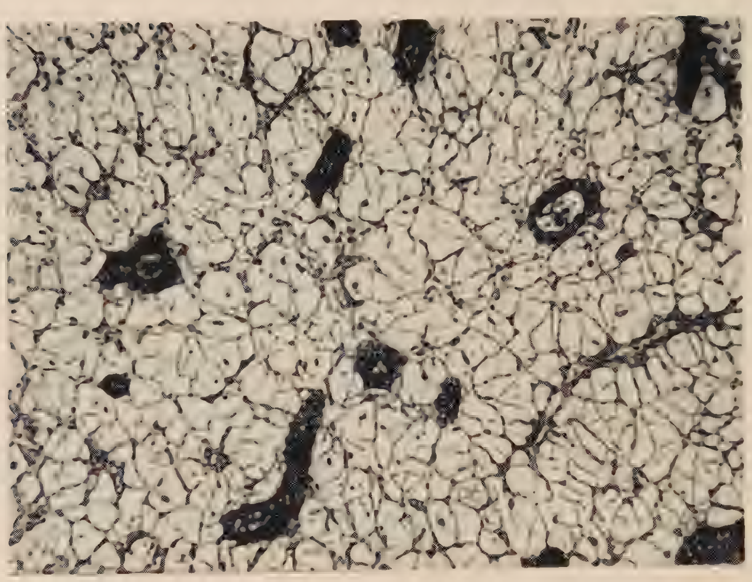
Attempts to induce spawning of the oysters of the three southern groups failed. None of the oysters released any spawn despite the fact that a combination of temperature and chemical stimuli was tried. The stimulated oysters moved their shells as in spawning but, nevertheless, released no eggs or sperm. It is possible that at that time the degenerative processes within the gonads had already progressed to such an extent that normal spawning became impossible.

TABLE I

Conditions of gonads of oysters originated in different geographical areas, kept in Milford Harbor, Conn. for about 2 years. End of spawning season, 1950

Area of origin	Conditions of gonads			Gonad thickness, range in millimeters	Average gonad thickness in millimeters
	Unspawned	Partly empty	Empty		
September 27 (20 oysters per sample)					
Wareham, Mass.	0	0	20	0.0	0.0
Long Island Sound	0	0	20	0.0	0.0
Cape May, N. J.	7	12	1	0.0–3.0	1.2
Seaside, Va.	10	8	2	0.0–3.0	1.6
James River, Va.	15	3	2	0.0–3.5	2.3
October 25 (10 oysters per sample)					
Wareham, Mass.	0	0	10	0.0	0.0
Long Island Sound	0	0	10	0.0	0.0
Cape May, N. J.	2	3	5	0.0–3.0	0.6
Seaside, Va.	4	5	1	0.0–3.5	1.7
James River, Va.	4	6	0	1.0–3.0	2.1

The second examination was made on October 25, 1950 when the temperature of the water in Milford Harbor had decreased to 14.0° C. On that occasion, however, only 10 oysters per sample were taken. The examination again emphasized the differences between the northern and southern groups. The two northern groups were, of course, again found with discharged gonads and in the process of accumulation of glycogen. The southern groups, however, still contained a considerable quantity of spawn (Table I). In the Cape May, N. J. group, half the oysters contained all or some spawn. Active sperm could still be found but eggs, as a rule, although



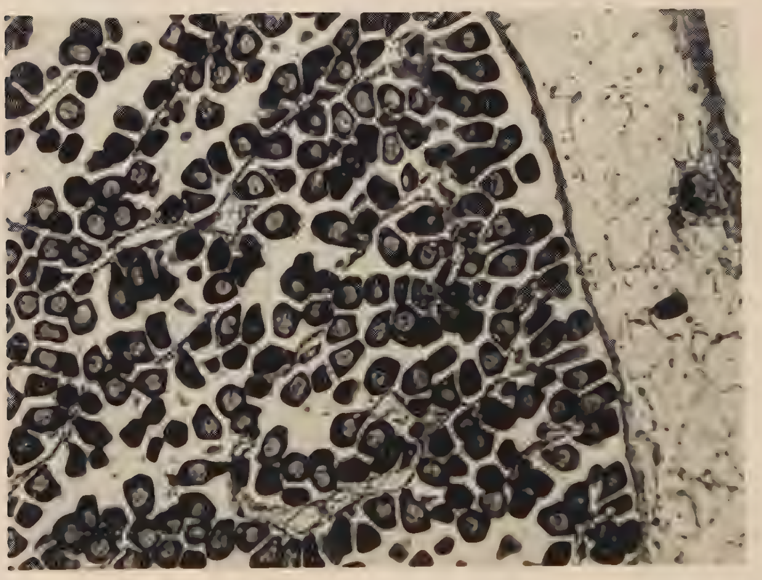


FIGURE 1. Section of gonad of Long Island Sound oyster preserved late in September, showing complete recovery from spawning. Small, undeveloped follicles, typical for post-spawning condition of oysters, are surrounded by masses of cells of the connective tissue. × 110.

FIGURE 2. Section of gonad of Virginia oyster preserved late in September, still containing fully developed undischarged eggs. × 110.

present in very large numbers, appeared to be abnormal. The color of the gonads changed from creamy white to grayish yellow, and instead of being soft and oozing, as was often noticed during the examination of September 27, the gonad material was hard. In almost all instances resorption of gonad material was in progress, the number of leucocytes and phagocytic cells being extremely large.

The other half of the New Jersey oysters had their gonads completely or almost completely devoid of spawn. Whether these oysters discharged the spawn in a normal way or whether their gonads were resorbed after failure to spawn, remained undetermined.

Somewhat the same conditions were observed in the two Virginia groups. However, only one out of 20 oysters had completely empty gonads. The others had either entirely undischarged gonads, or gonads that still contained large quantities of spawn. It was quite clear that at least 8 oysters of the 20 had never spawned (Table I). The thickness of the gonadal layer of the unspawned oysters was 3.0 mm. or more.

Our controlled experiments in Milford Harbor were collaborated by observations made on the oyster beds of Long Island Sound. A schooner load of oysters native to the Seaside of Virginia, south of Chincoteague, was brought to Connecticut by F. Mansfield and Sons Oyster Company and planted on the cultivated beds of the Company in Long Island Sound, south of West Haven, at a depth of approximately 10 feet. Examination of the gonads of these oysters made on several occasions late in the fall showed that many oysters did not release their spawn, while the local oysters living on the same bed were completely spawned by the middle or the end of September.

In general, our experiments have shown that the oysters which originated in Massachusetts or Long Island Sound, *i.e.,* in the more northern latitudes of the range in which *C. virginica* is found, spawned in Milford Harbor, Conn. during the summer of 1950, discharging all the spawn. However, the majority of the oysters that originated in warmer regions, New Jersey or Virginia, either did not spawn at all or discharged only a portion of the accumulated spawn. This difference indicates that the breeding temperature requirements of the northern oysters are somewhat lower than those of the southern groups. It also suggests that some physiological requirements of oysters of different geographical districts may be decidedly different. Consequently, it may be logically assumed that these groups of oysters, although all belonging to the same genus and species, *Crassostrea virginica* Gmelin, may, nevertheless, be distinct physiological races.

If, as our observations seem to indicate, there are different physiological races among the population of *C. virginica* of our Atlantic Coast, which require different temperatures for spawning, then, in addition to the theoretical interest of these observations, we are immediately faced with a number of considerations which may arise in connection with transplantation of oysters from one geographical district to another, especially a far removed one. For example, it has been shown that the oysters of Long Island Sound may begin to spawn at a temperature as low as about 16.0° C. (Loosanoff, 1939). Were these oysters transplanted to southern areas, they, as pointed out by Stauber (1950), would, under the new temperature conditions, begin to spawn far ahead of the local population. It is true that since spawning of a single oyster may continue for several weeks, some of the northern oysters may, at the end of their spawning period, crossbreed with the southern ones, which, requiring a higher temperature, would begin spawning later in the season. Nevertheless, because of the absence in the water of gametes of southern oysters during the largest part of the spawning of the northern races, most of the progeny of the northern oysters should remain to be of pure northern strain.

On the other hand, the majority of southern oysters transplanted to Long Island Sound, or other bodies of water in the north where the temperature seldom reaches and is practically never maintained for a prolonged period at 25.0° C., would not spawn. Such oysters, naturally, cannot be counted upon to contribute to the future increase of the local population.

Finally, the oysters with unspawned or partially resorbed gonads, of the type which were found in our samples of the southern groups on September 27 and October 25, 1950, would be virtually unsalable because of their poor quality. Obviously, the presence of southern oysters on the northern beds may not always be desirable because, while competing with northern oysters for space and food, they might neither participate in the increase of the local oyster population nor present a desirable food product.

In conclusion it should be mentioned that it is very fortunate for our studies that the summer of 1950 was comparatively cool, thus preventing the temperature of the water of Long Island Sound and particularly of Milford Harbor, from reaching an unusually high level, as happened during the record-breaking hot and long summer of 1949 when a temperature of 25.0° C. and higher was maintained for long periods. Under those conditions, of course, all oysters, including those of the three southern areas, would have spawned completely, leaving no evidence of the different temperature requirements of the different groups. In the past we found such to be the case with one group of oysters received from Eastern Bay, Maryland, which was kept in very shallow water in Milford Harbor near the shore where the temperature on some occasions was high enough to permit them to spawn normally.

We wish to express our thanks to our colleague, H. C. Davis, for his participation in the examination of gonads of the oysters, and to our friends in different parts of the country who were kind enough to ship us oysters for these studies.

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SPAWNING AND SETTING OF THE AMERICAN OYSTER, *O. VIRGINICA,* IN RELATION TO LUNAR PHASES

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Introduction and Review of Literature

A revival of interest in the relation between the lunar phases and periodicity in the breeding of marine animals has been recently stimulated by Korringa's (1947) article. Although his article is chiefly devoted to a review of the literature on this subject and its analysis, the author, nevertheless, incorporates in it his own observations on the periodicity of swarming of the larvae of the European oyster, *Ostrea edulis,* in the Oosterschelde, Holland, during the period from 1935 until 1946. Korringa's extensive data led him to the conclusion that in his district there is a well-defined periodicity in the spawning of *O. edulis* and swarming of its larvae, and that this periodicity is directly correlated with the phases of the moon.

Korringa found that the important maxima of extrusion of the eggs (heavy spawnings) into the mantle cavity of female oysters take place at the spring tides, occurring 2 days after full and new moon. About 8 days after spawning the larvae are released from the mother's mantle chamber and appear in the water in large numbers. This phenomenon, known as swarming, happens about 10 days after full or new moon. Of course, the dates of spawning are of primary importance because swarmings follow them almost automatically. Korringa thinks that periodicity in the spawning of *O. edulis* is caused by the rhythmical differences in the water pressure occurring between the neap and spring tides. According to Korringa (1947) "it is the rhythm of the tides which does the trick."

Since an extensive review of literature on the relation between the phases of the moon and the periodicity of spawning of marine animals has already been offered by Korringa, it is not necessary to discuss it at length in our paper. We shall confine ourselves to those references that concern oysters. Orton (1926), working in Fal-Estuary, England, on *O. edulis* came to the conclusion that there was a periodicity in its spawning, the maxima occurring near full moon. He thought, however, that periodical spawning was noticed only in normal oysters, while "dumpy" or irregularly-shaped oysters showed no such rhythm. Orton suggested that the rapid rate of change in hydrostatic pressure at the spring tides accompanied by an increase in temperature acted as a stimulus to induce spawning. Later on, however, Orton (1937) wrote that his further observations showed no relation between the maxima of spawning and the full moon tides, and that he never again observed lunar periodicity in the spawning of oysters.

Spärck (1929) working on the same species in Limfjord found no lunar periodicity in its spawning. However, since the tidal changes and the changes in hydrostatic pressure in Limfjord are small, the lack of periodicity there could be ascribed to that reason.

In this country the nearest relative of *O. edulis* is *Ostrea lurida,* a larviparous species, intensively cultivated in some sections of Puget Sound. A description of the spawning, larval development and setting of this oyster has been given by Hopkins (1937). Hopkins found no lunar periodicity in the spawning and swarming of *O. lurida,* but established that spawning is a continuous process extending for a period of at least 5 months, although it is most active for approximately 6 weeks. Once spawning begins, it usually slowly increases to a maximum and then gradually diminishes.

Schaefer (1937) studied spawning and setting of Japanese oysters, *Ostrea gigas,* introduced in Puget Sound. Spawning extended over a considerable period of time during the summer, but there was no correlation between the lunar phases and intensity of spawning. Schaefer thought, nevertheless, that he found a direct correlation between the rate of setting and "the lunar tidal period," because the modes of the curves of setting at all his three stations corresponded, in his opinion, with the periods of neap tides.

Schaefer's observations were made during one summer only. As will be shown later, the conclusions regarding the periodicity of spawning and setting of oysters may be misleading if based on a single summer of observations. Furthermore, a critical study of Schaefer's diagram fails to support his contention. For example, the largest peak of setting at one of his stations took place about August 22 during a neap tide period. However, the curve showing the intensity of setting at his second station was not only lacking a peak during the same period but actually showed a depression. The curve of his third station showed only insignificant variations in the intensity of setting between August 10 and September 17, and definitely lacked any pronounced peaks, which coincided with the neap tides.

Before proceeding with a review of the articles dealing with spawning of *Ostrea virginica* we should mention that our oyster differs in several important respects from its European relative, *O. edulis.* As a matter of fact, the anatomical and physiological differences of these two types of oysters are of such magnitude that many suggestions have been made to regard them as members of two different genera. One of the chief differences between them is that while *O. edulis* is larviparous, *O. virginica* is oviparous. *O. edulis* incubates the eggs, and later the larvae, in its mantle chamber for about 8 days before discharging them in the surrounding water. When discharged the larvae are already about 175 μ in length. The larvae lead a free-swimming life for about 8 to 10 days (temperature 18.0–19.0° C.) and then metamorphose into juvenile oysters, a process which in this country is called "setting" and in England, "spatfall" of oysters. *O. virginica,* on the other hand, discharges the eggs directly into the water. The eggs, which measure approximately 50 μ, soon develop into straight hinge larvae about 70–75 μ long. The free-swimming period is estimated by various writers to last from 7 to 30 days (Nelson 1908; Medcof 1939) depending upon ecological conditions.

Nelson (1928), while offering no observations on lunar periodicity, related the spawning of our oysters in Barnegat Bay, New Jersey, to temperature alone. Since no connection was shown between the times the spawning temperatures are reached and the phases of the moon, his observations lend no support to the theory of lunar periodicity.

Prytherch (1929) working on *O. virginica* in Milford Harbor and Long Island Sound expressed the opinion that in these waters the majority of the oysters spawned "at the end of the full moon tidal period, or eight days after the time of full moon." In other words, those spawnings took place during the neap tides, when the differences in hydrostatic pressure between high and low water are usually the smallest. He thought that the effect of the moon on the spawning of the American oyster is only indirect, and that the spawnings which occurred at the end of the full moon tidal periods took place then simply because of an increase in the water temperature at that time.

Hopkins (1931) working with the same species in Galveston Bay, Texas, wrote: "The period of greatest abundance of larvae in the water appears to have been from the middle of April to the middle of June. Since these larvae were predominantly in the straight hinge stage, or within about 3 days old presumably, the records may be considered to indicate the period of most profuse spawning." Obviously, Hopkins found no definite maxima spawnings that could be correlated with certain phases of the moon. It should be remembered, however, that in Galveston Bay where Hopkins worked the mean range of tide is small, about 1.1 feet and, therefore, the changes in hydrostatic pressure there are insignificant.

Loosanoff and Engle (1940) reported no periodicity in the spawning of *O. virginica* in Long Island Sound or in Milford Harbor during the summer of 1937.

As can be seen, very little has been written on the spawning of *O. virginica* in relation to the lunar phases. The lack of such contributions is easily understood if it is remembered that reliable conclusions on this subject can be formed only after working in the same locality for a number of years, as Korringa did in the Oosterschelde. This, of course, is not often possible. In this country the senior author is one of the few fortunate enough to have had the opportunity to study the propagation of oysters in the same locality over a long period. His observations have been made for the last 13 years, beginning with 1937, on the oysters, *O. virginica,* of Long Island Sound and some of its tributaries. Sufficiently complete data are now available to discuss certain aspects of the spawning behavior of our oysters and compare them with those of *O. edulis*.

Collection of the data offered in this article was made possible through the help of the many workers employed during the 13 summers of investigation. To them we owe our sincere thanks. We are especially obliged to Mr. James B. Engle, former Oyster Culturist of our Laboratory, who for several summers participated in the field work, counting oyster larvae in the water samples and oyster set on the collectors.

OBSERVATIONS AND EXPERIMENTS

Accumulation of spawn in different years

Before proceeding to discuss our observations on the periodicity of spawning and setting of oysters in Long Island Sound it may be worthwhile to consider one of the factors which may have a direct bearing upon the number of larvae found in different years. Korringa (1947), in discussing the differences in the production of larvae in the Oosterschelde from year to year, concludes that it is mainly governed by the number of mother oysters. This assumption would be justified only on the condition that the quantity of spawn developed by the oysters from year to year would always be the same. This, of course, is not so, at least for *O. virginica.*

We have already reported (Loosanoff and Engle 1940) that the thickness of the gonadal layer of Long Island Sound oysters, of approximately the same age and size, varied considerably from year to year. Since the publication of that report, much additional information on such fluctuations has become available (Fig. 1). It shows, for example, that in 1937 the average pre-spawning thickness of the gonadal layer was more than twice as great as in 1946. It is clear, therefore, that the quantity of spawn produced by a given number of oysters in a certain year may equal or even exceed the quantity produced by twice that number of oysters in some other year.

Since there is no evidence that *O. edulis* of a certain size invariably produces the same quantity of spawn every year, it is possible that the fluctuations in the quantities of spawn accumulated by European oysters in different years may resemble those of our oysters. Korringa's own data seem to indicate that. For example, the largest numbers of larvae in the Oosterschelde were recorded in 1939, 1945 and 1946, presumably, because the numbers of mother oysters present on the beds during those years were also the largest (Korringa 1947). Yet, he reports no such maximum for 1938, although the number of oysters during that year was the same as in 1945 or 1946.

A comparison of the number of larvae produced in the Oosterschelde in 1937 with that of 1938 shows an even greater inconsistency. Although in 1938 the number of mother oysters was only about 17

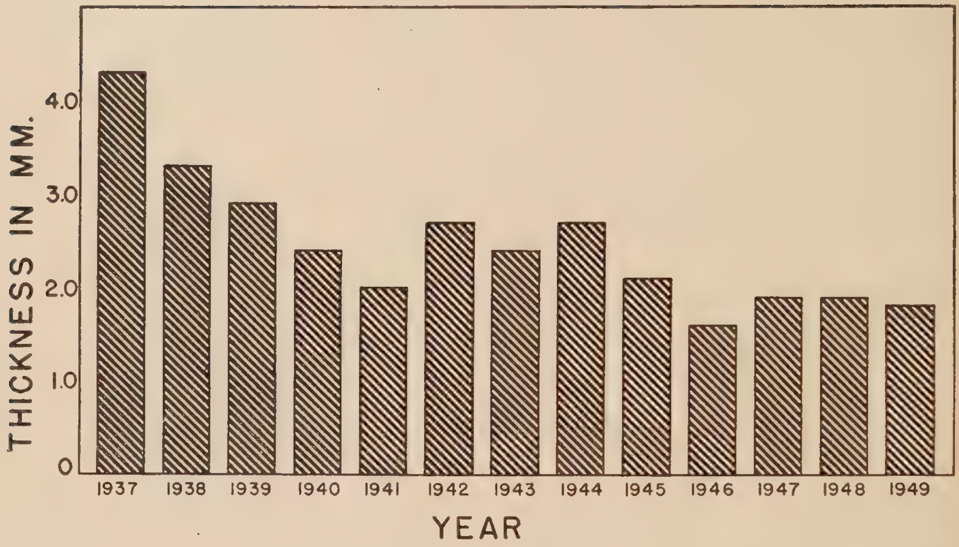

FIG. 1. Average pre-spawning thickness of gonadal layer of oysters of Long Island Sound, 1937–1949.

per cent larger than in 1937, the total production of larvae during 1938 was, according to Korringa's diagram, approximately 100 per cent greater than in 1937. Practically the same can be said in comparing the years of 1944 and 1945.

These examples are ample to show that the conception that the numbers of larvae produced in the different years should be roughly proportional to the numbers of mother oysters often does not hold true. Nevertheless, even if there is no direct ratio between the two numbers, it still should not be denied that the number of mother oysters is an important factor in governing the extent of the annual production of larvae. However, its importance varies from year to year, depending upon the physical condition of the oysters during the periods when accumulation of gonad material in their bodies is taking place, and also upon the ecological conditions which governed the accumulation of spawn. Obviously, an oyster population consisting chiefly of sick or poorly fed individuals cannot develop enough spawn to produce heavy numbers of larvae. Such is apparently the case shown by Korringa (1947) for the year 1936 when most of the oysters in the Oosterschelde were in poor condition.

To sustain further this argument it may be mentioned here that our field and laboratory observations of the past five years have shown that the quantity of spawn to be developed by oysters depends upon the quantity of glycogen and other nutritive materials stored in their bodies. Therefore, a large production of eggs can be expected only in the years when the bodies of the oysters are rich in glycogen. Since the quantity of glycogen during the pre-gonad formation period varies greatly from year to year, corresponding variations in accumulation of spawn should also be expected. This may explain why in certain years a small but healthy population can develop and discharge more spawn than a considerably larger population existing under unfavorable ecological conditions.

Occurrence and distribution of larvae

Observations of the last 13 years on the occurrence of oyster larvae in Long Island Sound showed consistently that their horizontal distribution over the oyster beds is extremely uneven. For example, the samples collected on July 26, 1944 at five stations of the New Haven area showed the number of larvae ranging from 0 to 800 per 25 gallons of water. Because the stations were located within a short distance of each other the entire collection was completed within 1 hour and 30 minutes. The collection was repeated on July 29, August 24 and 27 of the same year and again showed extremely wide variations among the samples.

In comparing the number of larvae present on the same day in the three major districts, New Haven, Milford and Bridgeport, all of which are included in the most important part of the Long Island Sound oyster-producing area, where more than a million bushels of oysters capable of spawning are kept, the same inconsistency exists. Often when larvae were found in one district, they were almost entirely absent in the one or two others. Prytherch (1928), who also spent several summers studying the propagation of oysters in Long Island Sound, found that the abundance and distribution of larvae in the region between Bridgeport and New Haven were extremely irregular.

Because of such large differences in the number of larvae found at about the same time in different parts of the oyster-producing section of Long Island Sound and especially at closely located stations, it appears improbable that there are definite periodical maximum spawnings involving the largest part of our oyster population, such as Korringa (1947) found in the Oosterschelde. Our observations on the changes in thickness of the gonadal layer of the oysters of Long Island Sound also indicate that the discharge of spawn during the summer is quite slow and gradual without sharp decreases in the thickness that would coincide with the periods of new or full moon (Loosanoff and Engle 1942).

The absence in our waters of a definite relation between the dates of heavy spawnings and the periods of the spring tides is best illustrated by observations on the changes in the numbers of larvae at one of our stations where the samples were systematically collected during three summers. This station was located in Milford Harbor near its junction with Long Island Sound. The method consisted in pumping 25 gallons of water into

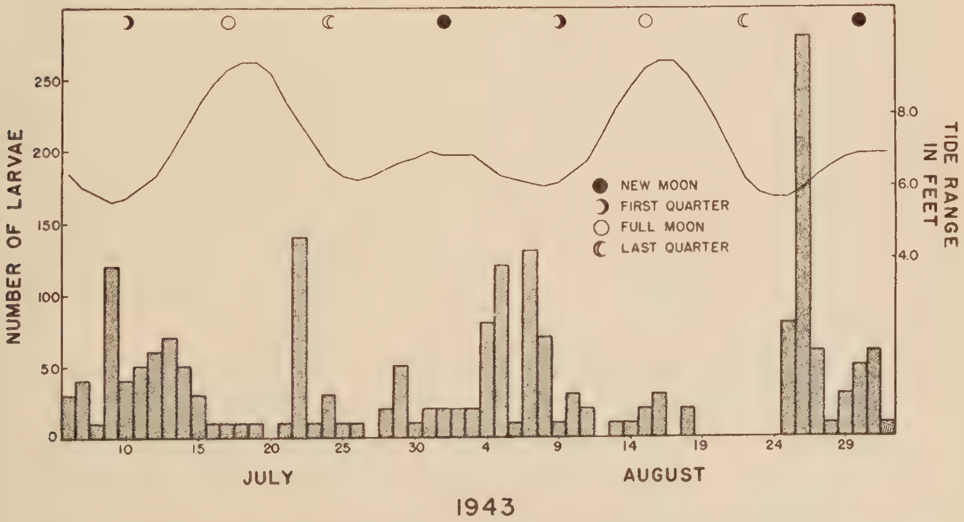

Fig. 2. Numbers of straight hinge oyster larvae per 25 gallons of water collected daily in Milford Harbor during the summer of 1943. Tide range in feet and lunar phases are also shown.

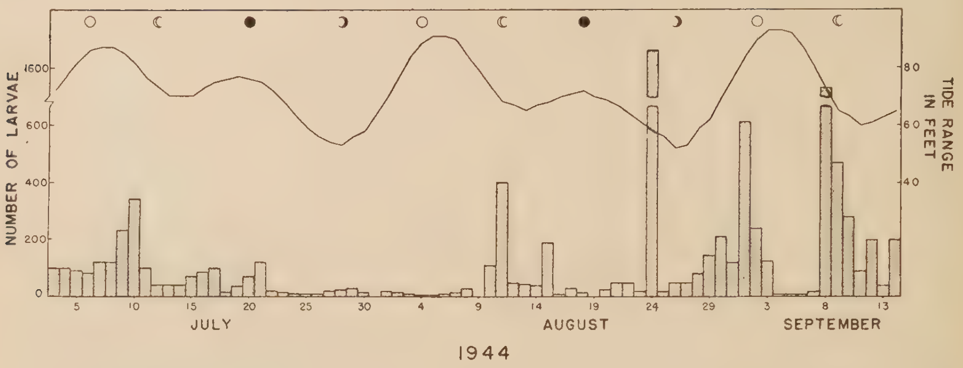

Fig. 3. Numbers of straight hinge oyster larvae per 25 gallons of water collected daily in Milford Harbor during the summer of 1944. Tide range in feet and lunar phases are also shown.

a barrel of that capacity and then filtering the collected water through a plankton net. Toward the end of the filtering the water in the barrel was strongly agitated to keep all the plankton in suspension. The samples, which were collected daily, were taken 3 feet below the surface. Counting of the larvae, a slow and tedious process when the samples were rich in plankton, was made in the usual manner using a microscope and Sedgwick-Rafter counting cell.

The samples were collected during July and August in 1943 and 1945, while in 1944 the collection was extended until the middle of September. The results of the three years of observations are given in Figures 2, 3 and 4. Only straight hinge larvae, not over 80 microns in length, thus indicating that they were developed

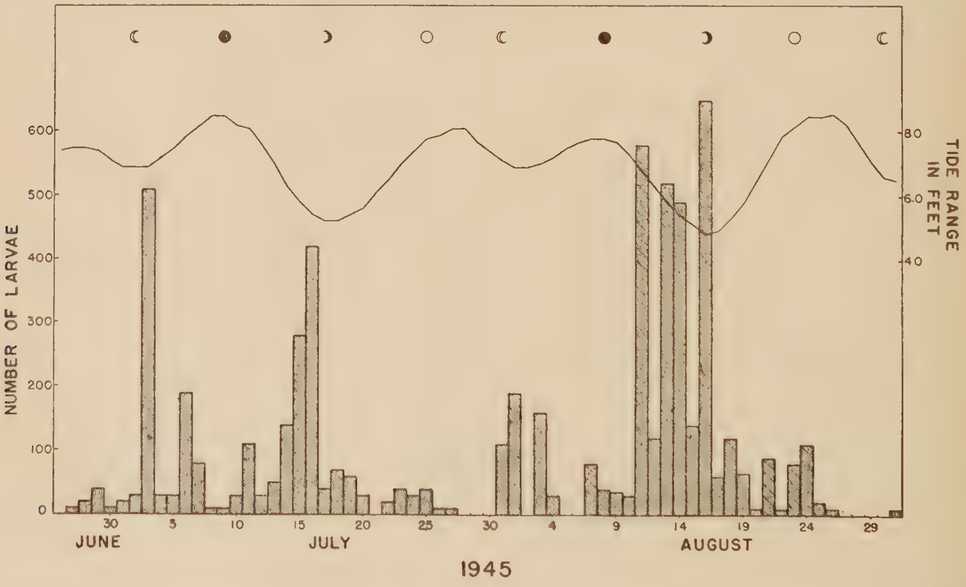

Fig. 4. Numbers of straight hinge oyster larvae per 25 gallons of water collected daily in Milford Harbor during the summer of 1945. Tide range in feet and lunar phases are also shown.

from eggs spawned about 24 to 36 hours prior to collection, are shown.

Perhaps the most important feature common to all three years is that with a few exceptions the larvae were usually least numerous near the new and full moon phases. This observation is directly opposite to that made by Korringa in the Oosterschelde, where he found that "spawning must have had its maxima roundabout the spring tides which occur about 2 days after full and new moon." Our data seem to indicate, on the contrary, that the peaks in the number of straight hinge larvae were usually found near the first or last quarter of the moon (Figs. 2–4). In some instances these peaks either coincided with those phases or occurred one or two days before or after them.

After studying these data one may conclude that in our waters there also are spawning maxima which, however, happen at lunar periods directly opposite to those coinciding with the heavy spawnings of Holland oysters. However, we should hesitate to accept this conclusion because of the following considerations: First, a closer examination of the diagrams would show that although the peaks in the number of straight hinge larvae were often near the first or last quarter of the moon they, nevertheless, did not occur with definite regularity. While many preceded these phases by a day or two, others, such as the peak of July 3, 1945, followed them. In still other instances, as about July 28, 1944, no peak whatsoever was recorded during the first quarter. On the other hand, the peak of September 1, 1944, happened near full moon. Finally, as between August 11 and 16, 1945, large numbers of young larvae were found in the water for several days indicating a continuous and prolonged heavy spawning.

Secondly, the data on the daily number of larvae are available from one station only. In our opinion they are not sufficient for forming a reliable conclusion for the entire oyster-producing section of Long Island Sound. Nevertheless, the data are important in showing that in the area where daily samples were taken there were no definite spawning maxima correlated with the spring tides, occurring about 2 days after new or full moon. On the contrary, the presence of large numbers of young larvae at and near the periods of neap tides suggests that although no well-defined lunar periodicity was observed, the oysters may spawn somewhat more profusely during these phases.

Observations on spawning and setting

In addition to our observations on the daily numbers of larvae we have accumulated other data which may help us decide whether spawning and also setting of oysters in our waters are of a periodical type governed by the lunar phases. These data are based on the observations of the last 13 years, starting in 1937 and including 1949, on the dates of the beginning of spawning and on the dates and intensity of setting in Long Island Sound. We shall start with a discussion of the events prevailing at the beginning of each spawning season.

The beginning of spawning was determined by frequent gross and microscopic studies of oyster gonads and by establishing the date of the first appearance of larvae. Semi-weekly cruises were begun toward the end of June for the collection of samples at all our stations located throughout the most important oyster-producing section confined between New Haven and Bridgeport. The stations were located at approximate depths of 10, 20 or 30 feet. The number of stations established in different years varied from 10 to 19. In addition to the main stations of Long Island Sound several substations were kept in more shallow places, such as Milford Harbor.

When the date of spawning was approaching, many samples, in addition to those taken on the regular trips, were collected daily, or almost daily, from several beds of Long Island Sound and from

Milford Harbor. This method allowed us to determine to a day, or almost to a day, the date of the beginning of spawning.

In our waters the spawning season may be begun by a comparatively few oysters releasing some eggs. Other oysters will follow somewhat later, and in some years ripe but unspawned oysters may be found as late as six weeks after the beginning of the spawning season (Loosanoff and Engle 1942).

Judging by the presence of a few partially spawned oysters, spawning begins about the same time at the majority of stations. The notable exception was the year 1941 when the inshore shallow water oysters began to spawn on July 2, while the oysters living at a depth of about 10 feet and more did not spawn until July 9. We prefer to consider July 2 as the date of the beginning of spawning because the larvae developed from the eggs discharged on that day set later on in considerable numbers, thus commencing the setting season.

Spawning in Long Island Sound begins during the last few days of June or during the first days of July (Fig. 5). The earliest date of spawning recorded was in 1945 and 1949, on June 26, and the latest, in 1937 and 1940, on July 3. Thus, in 13 years the beginning of spawning was confined to the calendar period of only about 8 days.

The beginning of spawning occurred at every phase ranging from new moon to the last quarter (Fig. 5). In 9 out of 13 years it took place near new or full moon. However, it did not occur with any regularity either before or after those phases but with considerable variation in both directions. For example, in 1939, 1940, 1943 and 1947 spawning began 2 or 3 days before new or full moon, in other words, 5 or 6 days before the spring tides, too far away to be regarded as caused or induced by the hydrostatic conditions prevailing at such tides. Considering these circumstances and also that in the four other years spawning began at, or very close to, the first or last quarter it may be concluded that the beginning of spawning is not confined to a certain lunar phase.

YEAR	MONTH AND DAY	MOON PHASE	TIDE RANGE IN FEET	DEPARTURE FROM MEAN TIDE RANGE
1937	7-3	☾ +2	7.0	+0.4
1938	6-28	● +1	9.6	+3.0
1939	6-29	○ -2	8.1	+1.5
1940	7-3	● -2	7.2	+0.6
1941	7-2	☽	7.1	+0.5
1942	6-29	○ +1	9.6	+3.0
1943	6-29	● -3	7.1	+0.5
1944	6-28	☽	5.2	-1.4
1945	6-26	○ +1	7.4	+0.8
1946	7-1	● +2	8.8	+2.2
1947	7-1	○ -2	6.8	+0.2
1948	6-30	☾ +1	5.3	-1.3
1949	6-26	●	7.4	+0.8
MEAN RANGE OF TIDE 6.6 FEET SPRING RANGE OF TIDE 7.7 FEET				

Fig. 5. Dates of the beginning of spawning during the 13-year period, and moon phases, tide range and departure from mean tide range prevailing at those dates. Signs of plus or minus and numerals indicate that the events shown at the head of the column took place that many days before or after the exact dates of indicated lunar phases.

The beginning of spawning was not related to definite tidal changes and, therefore, changes in hydrostatic pressure (Fig. 5). In Long Island Sound the mean range of the tide is 6.6 feet, and the spring range, being 7.7 feet, is 1.1 feet above the mean range. Were we to assume that spawning begins on the spring tides, about 2 days after full or new moon, and that it is caused by the rhythmical sequence of differences in the water pressure between the neap and spring tides, we would find little support in our data. Only four times in 13 years did spawning begin during the tide range of 7.7 feet or more (Fig. 5). During the same period departure from the mean tide, at the onset of spawning, ranged from + 3.0 to − 1.4 feet. It is noteworthy that in 1944, a year of good oyster set, the beginning of spawning occurred when departure from the mean tide range was as much as − 1.4 feet.

On the basis of the data discussed above we may form the conclusion that in Long Island Sound the beginning of spawning of oysters should be expected on June 30 ± 4 days, independently of the lunar phases and of the rhythmical changes in hydrostatic pressure resulting from departure from the mean tide range.

Another important event in the propagation of oysters, that may lend itself to the analysis of periodicity, is the metamorphosis of larvae or, as it is commonly called, setting. Because the daily intensity of setting changes sharply during the summer, it is easy to ascertain whether these changes occur with regular periodicity.

The method employed in observations on the beginning, extent and the end of setting of oyster larvae in Long Island Sound has already been described (Loosanoff and Engle 1940). Here it is sufficient to say that with the aid of dissecting microscopes, the oyster set was examined and counted on the surfaces of the oyster shells taken from the collectors brought in twice a week from all our Long Island Sound stations. The collectors were poultry wire-mesh bags filled with clean oyster shells. The shells were always discarded after examination never again to be used in the collectors.

The data on the daily intensity of setting, if used as a proof of the presence or absence of periodicity, should be employed rather cautiously because the intensity depends not only on the number of eggs originally discharged by the oysters on any given day, but also on the rate of survival of the larvae that developed from those eggs. It is possible that a light spawning may give a comparatively heavy set if the mortality of the larvae is low, while a heavy spawning may result in a complete failure if the larvae do not survive. This contention is to some extent corroborated by our field observations (Loosanoff and Engle 1940). Nevertheless, it is thought that within as long a period as 13 years, periodicity, if such exists, should manifest itself regardless of numerous variables which may tend to shade it.

The length of the free-swimming period of the oyster larvae of Long Island Sound has never been accurately determined. Our observations show that the number of days elapsing between the beginning of spawning and the appearance of the first set ranges from 13 to 24, and averages 18.5 days (Fig. 6). The shortest period of 13 days was recorded in 1941, and the longest of 24 days, in 1943. Since, with the exception of 1943, the larval period was never longer than 20 days, it is possible that in 1943, a year when setting of oysters was extremely light, none of the larvae, which hatched from the eggs discharged during the first few days of the season, survived to reach the setting stage.

We found that in Long Island Sound the time and intensity of setting do not follow a rigid pattern from year to year. Nevertheless, in most instances there are at least two distinct waves of setting with definite maxima or peaks. The exceptions were the summers of 1943 and 1949 when second waves were practically nonexistent. The beginning of setting, which usually is also the beginning of the first wave of setting, and the dates of the peaks of the different waves of setting can be quite accurately determined from our records. However, the beginning of the second wave of setting is not always easy to ascertain because in some years setting may continue throughout the summer without having any blank period between the end of the first and the beginning of the second waves. In these cases, which hold true only for 2 or 3 years, the date of the beginning of the second wave was considered to be the day of the beginning

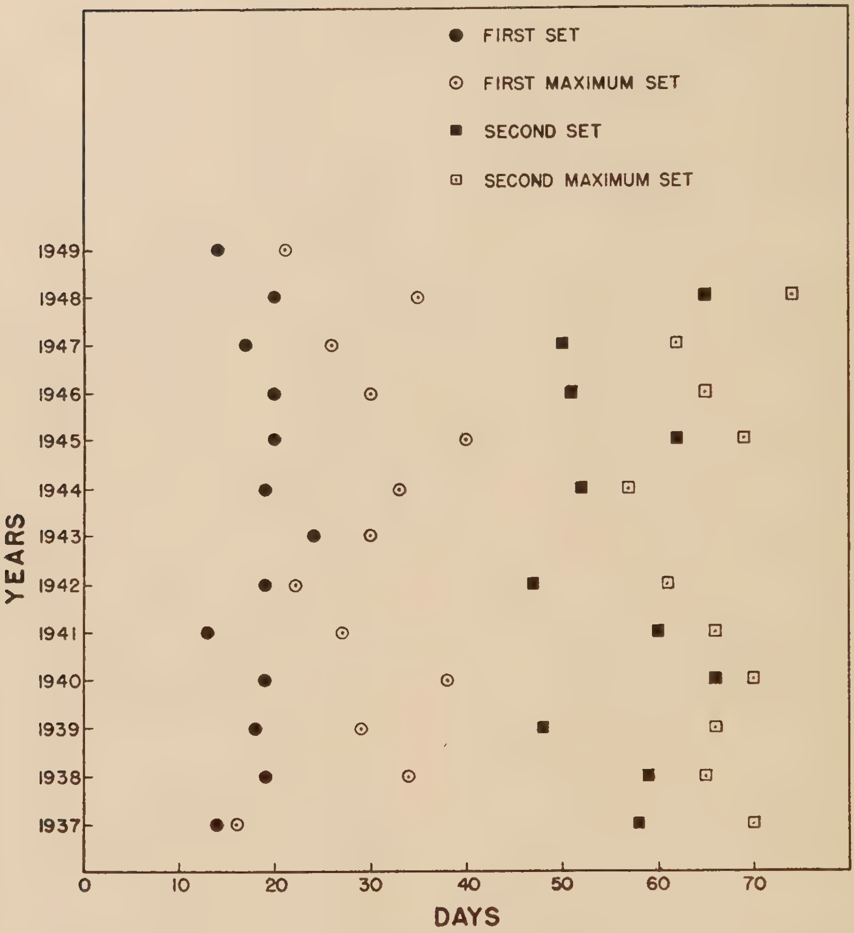

FIG. 6. Days elapsing between the beginning of spawning in each of the twelve years (1937–1949) and dates of first setting, maximum setting of first wave, beginning of second wave of setting, and maximum setting of second wave.

of the trend leading to the second peak of setting.

The following discussion can be better understood by studying Figure 7, which is offered here as an illustration summarizing some of our observations on the daily intensity of setting in Long Island Sound in one of the years of our studies. Similar data and figures are available for the other years. The columns of Figure 7 represent the sum of the daily set in 1948 on the collectors from all our stations located in different areas of the Sound.

The peaks of the waves varied considerably in magnitude in different years and within the same year. In several instances, as in 1948, the two waves of setting were of about the same importance and their peaks were of approximately the same height (Fig. 7). In other years one of the waves decidedly predominated, the other representing only a small percentage of the total annual set. There was no regularity in the relative importance of the two waves because in some years the first wave was the heavier, while in others it was the lighter of the two.

Although in each wave a single day appeared as the peak, the periods of heavy setting were not confined to those culminating points. Often, as happened in 1948 (Fig. 7), heavy setting, although somewhat varying in intensity, continued quite steadily sometimes as long as 8 to 10 days. This setting may be justifiably regarded as resulting from the continuous heavy spawnings preceding the settings by approximately 18 days, our average figure for the length of the larval period.

In 1948 the beginning of setting was recorded on July 21, about 20 days after the first spawning. The setting showed two well-defined waves (Fig. 7). The beginning of the first was on July 21, and its peak, on August 5, or about 35 days after the beginning of spawning. The second wave, which in 1948 was especially well defined by a long blank period prior to it, began on September 4, 65 days after the beginning of spawning, and its peak, recorded on September 12, was 74 days after the beginning of spawning.

In the 13 years the periods elapsing between the beginnings of spawning and the maximum setting, or the peak of the first wave, varied considerably from year to year ranging from 16 to 40 days and averaging about 30 days (Fig. 6).

The beginning of the second wave of setting varied from 47 to 66 days and averaged 56 days after the beginning of spawning (Fig. 6). In 1943, which was the year of almost complete failure of setting, and in 1949, the second waves were represented only by a few scattered spat at some stations, without showing a definite peak. Because the second waves of 1943 and 1949 were virtually absent, they will not be discussed in this paper.

The maximum daily set of the second wave occurred from 57 to 74 days and averaged 66 days after the beginning of the spawning season (Fig. 6).

Having established the time relation of some of the important events in the propagation of oysters in Long Island Sound we may proceed now to discuss whether these events are confined to certain lunar phases. These events are: the beginning of spawning, beginning of setting, day of maximum setting of the first wave, beginning of second wave of setting, and the day of maximum setting of the second wave.

The conditions at the beginning of spawning have already been discussed and are summarized in Figure 5. It was con-

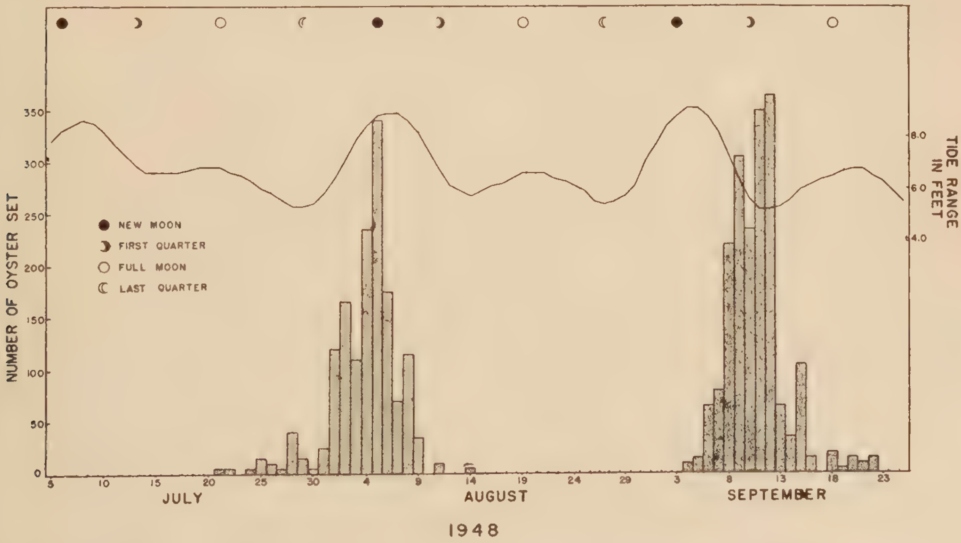

FIG. 7. Daily intensity of setting per 100 shells at ten collecting stations, Long Island Sound, 1948. Lunar phases and daily tide range are also shown.

YEAR	MONTH AND DAY	MOON PHASE	TIDE RANGE IN FEET	DEPARTURE FROM MEAN TIDE RANGE
1937	7-17	☽+2	5.4	-1.2
1938	7-17	☾-3	6.7	+0.1
1939	7-17	●+1	9.5	+2.9
1940	7-22	○+3	7.0	+0.4
1941	7-15	☾-1	5.8	-0.8
1942	7-18	☽-3	6.6	0.0
1943	7-23	☾-1	7.2	+0.6
1944	7-17	●-3	7.5	+0.9
1945	7-16	☽-1	5.4	-1.2
1946	7-21	☾	6.7	+0.1
1947	7-18	●	9.0	+2.4
1948	7-21	○	6.8	+0.2
1949	7-10	○	7.7	+1.1

FIG. 8. Date of beginning of setting in Long Island Sound in each of the 13 years of observations (1937–1949) and phase of moon, tide range in feet, and departure from mean tide range prevailing at each date.

cluded that the beginning of spawning is not confined to a definite lunar phase.

The earliest beginning of setting was recorded in 1949, on July 10, and the latest, in 1943, on July 23 (Fig. 8). Thus, in 13 summers of observations the beginning of setting was confined to 14 calendar days. However, if, because of the unusual weather conditions prevailing in 1949 we could assume that that summer was an atypical one, then the period could be shortened to only 9 days—July 15–23. Such an assumption is justifiable because of the hiatus existing between the dates of July 10 and 15 (Fig. 8), which indicates that such an early beginning of setting as occurred in 1949 was an unusual phenomenon.

The beginning of setting happened at every moon phase (Figs. 8, 9). In six years it took place at or near full or new moon, while during the seven other summers it occurred either near the first or last quarter. In general, during the 13-year period all four phases were almost evenly represented. Obviously, there was no correlation between the beginning of setting and a definite lunar phase.

The beginning of setting was not confined or even closely related to a certain tide condition (Fig. 8). The tide range on the days of setting varied from 5.4 feet in 1937 and 1945, to 9.5 feet in 1939, and the departure from the mean tide range varied from − 1.2 to + 2.9 feet. In three years setting began when the tide range was less than 6.6 feet, which is our mean range, and only on two occasions, 1939 and 1947, did the beginning of setting happen on the days when the tide range was above 7.7 feet. In three years setting began when the departure from the mean tide range was on the minus side (Fig. 8).

After considering the circumstances under which setting began during the period of our observations we may offer a provisional formula for the prediction of the beginning of setting of oyster larvae in Long Island Sound. The formula is as follows:

The beginning of oyster setting in Long Island Sound should be usually expected on July 19 ± 4 days, regardless of lunar phases and of changes in hydrostatic pressure caused by changes in the tidal level.

This formula is based upon our observations which, we believe, are extensive enough to justify suggesting it. It should be found correct in a majority of instances. Nevertheless, we do not maintain that it is infallible because some extremely abnormal conditions, such as encountered in 1949, may so affect the oysters or their larvae that the beginning of setting may happen outside the limits given in the formula. Furthermore, the possibility always remains that the larvae emerging from the eggs discharged during the first few days of the spawning season may perish and, as a consequence, the beginning of setting may be delayed until the larvae from later spawnings reach the state of metamorphosis.

The maximum setting of the first wave took place at all moon phases (Fig. 9). In about half the instances it occurred near the first quarter, a circumstance that may be important. This importance becomes even more significant if it is understood that the maximum setting of 1939 and 1944, which in our Figure 9 is shown to occur three days before full moon, can also be interpreted as occurring five and four days after the first quarter. The set of 1946 shown as taking place three days after the new moon can also be shown as happening four days before the first quarter.

Thus, in nine out of thirteen years the day of maximum setting of the first wave occurred near the first quarter. More detailed studies of the data will show, however, that in these nine years maximum setting took place from four days before the date of the first quarter to five days after it, thus extending over a range of 10 days (Fig. 9). Such a period is too long to be included within the short lunar period of one or two days, as Korringa (1947) finds almost always prevailing when a heavy spawning of Holland oysters or a heavy swarming of their larvae takes place. Furthermore, in two other years, 1943 and 1945, the maximum setting was recorded three days before new moon, in other words, 11 or 12 days before the first quarter, and in 1948 it took place on the date of new moon. These observations show that the date of maximum setting of the first wave is not sharply confined to the period of the first quarter or any other lunar phase.

Moreover, as has already been mentioned, heavy setting usually is not completed in a single day, but may continue, with some variations in intensity, for more than a week. For example, in 1948 the period of heavy setting of the first wave extended from August 1 to August 8 (Fig. 7). In relation to the lunar condition it began on the third day after the last quarter and continued 4 days past the new moon date. Obviously, even if in some cases the date of maximum setting coincides or closely approaches a certain

YEAR	MOON PHASES			
	BEGINNING OF SETTING	MAXIMUM SETTING FIRST WAVE	BEGINNING OF SECOND SETTING	MAXIMUM SETTING SECOND WAVE
1937	☽+2	☽+4	☾+2	☽-1
1938	☾-3	☽-2	●+1	☽
1939	●+1	○-3	●+1	☾-3
1940	○+3	☽	☽-1	☽+3
1941	☾-1	☽-2	☽+2	○+1
1942	☽-3	☽	●+3	○+3
1943	☾-1	●-3	—	—
1944	●-3	○-3	●+2	☽-1
1945	☽-1	●-3	☾-3	●-3
1946	☾	●+3	☾+1	☽+1
1947	●	☽+3	☽-3	○+1
1948	○	●	●+1	☽+2
1949	○	☾-1	—	—

FIG. 9. Moon phases prevailing at the dates of beginning of setting, maximum setting of first wave, beginning of second wave of setting, and maximum setting of second wave. Long Island Sound, 1937–1949.

moon phase, the significance of such an event is considerably lessened because the actual period of heavy setting may be so long that during it the changes in the tidal range may go from one extreme to another.

The beginning of the second wave of setting was observed at all phases except full moon (Fig. 9). In five years it occurred near new moon, while during the other six years it was equally divided between the first and last quarter periods. It is clear that in this case there was no relation between it and a definite lunar phase.

The maximum setting of the second wave occurred, as in the first wave, most often near the time of the first quarter. This happened 6 times in 11 years (Fig. 9). It is important, however, that in the other five years it took place at the three other lunar periods, the dates of the setting being removed from the first quarter by 10 days or more. In 1943 and 1949 the second waves of setting were too light to show maxima.

The observations on the second wave seem to minimize somewhat the importance of the first quarter as the period when maximum sets should be expected. Nevertheless, because most of the peaks of both waves happened around the first quarter we may consider this phase, if any lunar periodicity exists, as the period around which our heavy sets are most likely to occur. However, in offering this suggestion it is not implied that the dates of maximum sets in our waters occur with

YEAR	SPAWNING				SETTING		
	ASSUMED DATE OF SPAWNING	MOON PHASE	HIGH HIGH WATER IN FEET	DEPARTURE FROM MEAN TIDE RANGE	MONTH AND DAY	MOON PHASE	DEPARTURE FROM MEAN TIDE RANGE
1937	7-2	☾ +1	7.1	+0.3	7-19	☽ +4	-0.8
1938	7-14	○ +2	6.8	+0.1	8-1	☽ -2	+0.7
1939	7-10	☾ +1	6.5	-0.9	7-28	○ -3	+0.8
1940	7-23	○ +4	6.6	-0.1	8-10	☽	+0.6
1941	7-11	○ +3	7.6	+1.9	7-29	☽ -2	+1.1
1942	7-3	☾ -2	7.2	+1.0	7-21	☽	0.0
1943	7-11	☽ +1	6.6	-0.6	7-29	● -3	+0.1
1944	7-14	☾ +2	7.2	+0.4	8-1	○ -3	+0.4
1945	7-18	☽ +1	6.2	-1.4	8-5	● -3	+0.9
1946	7-13	○ -1	7.0	+0.2	7-31	● +3	+1.4
1947	7-9	☾ -2	6.3	-0.9	7-27	☽ +3	-0.8
1948	7-18	○ -3	7.0	+0.1	8-5	●	+2.2
1949	6-29	● +3	7.4	+0.9	7-17	☾ -1	-1.4

FIG. 10. Moon phases and tidal conditions existing at the dates of spawnings which presumably caused maximum setting of first wave. Long Island Sound, 1937–1949.

YEAR	SPAWNING				SETTING		
	ASSUMED DATE OF SPAWNING	MOON PHASE	HIGH HIGH WATER IN FEET	DEPARTURE FROM MEAN TIDE RANGE	MONTH AND DAY	MOON PHASE	DEPARTURE FROM MEAN TIDE RANGE
1937	8-24	○ +2	7.8	+1.8	9-11	☽ -1	-1.6
1938	8-14	○ +3	7.2	+0.7	9-1	☽	-1.2
1939	8-16	● +1	8.4	+3.2	9-3	☾ -3	+0.3
1940	8-24	☾ -2	6.6	-0.7	9-11	☽ +3	+0.1
1941	8-19	● -3	6.7	-0.4	9-6	○ +1	+1.4
1942	8-11	● -1	7.1	+0.5	8-29	○ +3	+1.2
1943							
1944	8-7	○ +3	8.0	+2.4	8-25	☽ -1	-1.0
1945	8-16	☽	6.1	-1.8	9-3	● -3	+0.3
1946	8-17	☾ -3	7.3	+0.8	9-4	☽ +1	-1.7
1947	8-14	● -2	7.7	+1.5	9-1	○ +1	+0.3
1948	8-25	☾ -2	6.6	-0.7	9-12	☽ +2	-1.4

FIG. 11. Moon phases and tidal conditions existing at the dates of spawnings which presumably caused maximum setting of second wave. Long Island Sound, 1937–1948.

the regularity resembling that of spawning or swarming of European oysters, where the maxima are sharply defined and are confined to one or two days of certain lunar periods (Korringa 1947). On the contrary, in Long Island Sound maximum sets took place in all four lunar periods. Even if many of those occurred near the first quarter, they sometimes happened 3 to 4 days either before or after the exact date of that lunar phase, thus being extended over a long period during which the tidal conditions varied considerably.

Further indication of the absence of periodicity was a lack of uniformity in the departures from the mean tide range during the dates of maximum set of the two waves. These data are given in the right halves of Figures 10 and 11. For the first wave these departures range from − 1.4 to + 2.2 feet, and for the second from − 1.7 to + 1.4 feet. In neither case was there any conclusive evidence that the maximum sets occurred when the departures from the mean tide range were of certain magnitudes. In general, of the 24 maxima of the first and second waves one happened when the departure was 0.0, eight when it was on the minus side, and 15 when it was on the plus side.

TABLE I. *Number of days elapsing between the dates of maximum setting of first and second waves, Long Island Sound, 1937–1948*

Year	Days	Year	Days
1937	53	1943	—
1938	30	1944	23
1939	36	1945	28
1940	31	1946	34
1941	38	1947	35
1942	38	1948	37

Searching further for signs of periodicity in the occurrence of the peaks of the two waves of setting a table was made to show the number of days elapsing between the dates of maximum settings of each year (Table I). The longest period between the two peaks was recorded in 1937, when 53 days elapsed between these two events. The shortest period of 23 days was noted in 1944. In the remaining years the period between the two peaks ranged between 28 and 38 days.

The lunar month is approximately 28 days. Only in 1945 did the number of days elapsing between the peaks of the two waves coincide with this figure. This eliminates the possibility of a monthly periodicity, i.e., a dependence upon a single lunar phase. If a semi-monthly periodicity were involved, as is the case of heavy spawnings of the European oyster (Korringa 1947), then the peaks would be expected to occur at intervals of 14 days. That such periodicity does not exist is shown by our data (Table I).

It is interesting that in six years the period elapsing between the two peaks was from 34 to 38 days, and the average, 36 days. The latter figure would be equal to one lunar month of 28 days plus a period roughly equal to that elapsing from one phase of the moon to the next. Obviously this does not indicate a periodic activity associated with a definite lunar phase and the corresponding tidal condition.

Since the dates of maximum sets are accurately determined, we may try to use this knowledge to ascertain the dates of the spawnings which caused these sets, and subsequently determine during what lunar phases and under what tidal conditions these spawnings took place. We know that the average length of the larval period in our waters, at least during the early part of the season, is about 18.5 days. Therefore, we can go back that number of days from the dates of maximum sets and determine the approximate dates when the spawnings responsible for these sets occurred. Because maximum sets occur in the middle of the summer, when the temperature is usually somewhat higher than at the beginning of the season and, therefore, development of larvae may proceed more quickly, we shall take 18 days, instead of the average of 18.5, for our estimations.

In offering the above-described approach we wish to mention that its accuracy is only relative, because of the differences in the ecological conditions under which larvae have to exist during different years. Nevertheless, it is again believed that periodicity, if such existed, would display itself within a period of 13 years, even if other factors would tend to mask it.

As is shown in the left half of Figure 10, the spawnings that presumably caused the maximum sets of the first waves took place near all four lunar phases. Only once, in 1949, did it take place near new moon, the period when the range of tide in Long Island Sound is greatest. This is in disagreement with observations on the behavior of *O. edulis* of Holland where maximum spawnings usually take place at the height of the spring tides. In five years the spawnings took place near the last quarter, in other words, during neap tides when the range of tide and the differences in hydrostatic pressure were small. This, again, disagrees with observations on the spawning behavior of the oysters of Holland. In two other years, 1943 and 1945, maximum spawning also took place at neap tides one day after the first quarter. In the remaining five years, however, spawning took place near full moon.

It is rather interesting that not once in thirteen years did the date of spawning coincide with the high tide of 7.7 feet or higher (Fig. 10).

Departure from the mean tide range varied at the time of spawnings from − 1.4 to + 1.9 feet, and in five instances spawnings resulting in maximum sets took place during the times when the departure from the mean tide range was on the minus side (Fig. 10).

In analyzing the events of the second wave we will find that the spawnings causing the maximum sets took place at all four lunar phases (Fig. 11). In four years the spawnings took place near the time of new moon, a condition which occurred only once in connection with the first wave. This once more showed the lack of a definite pattern in the relations between the time of the spawnings and the lunar phases.

There was no consistent relation found between the dates of spawnings and the height of high water reached on such dates (Fig. 11). Moreover, the variations in departure from the mean tide range were even greater than recorded for the first wave. These departures varied from − 1.8 to + 3.2 feet. In four years spawnings took place when departure from the mean tide range was on the minus side (Fig. 11).

In summarizing the analysis of the conditions existing during the days when the spawnings presumably responsible for the maximum sets of both waves took place it may be concluded that there is no evidence that these spawnings occurred with a definite regularity which was controlled or influenced by the lunar periods and, therefore, by the corresponding changes in hydrostatic pressure. On seven occasions the spawnings coincided with the spring tide periods (one to three days after new or full moon). On five other occasions they happened at or near the neap tides. In the remaining instances they took place at different intermediate points lying between the two extremes. In nine cases out of 24 the spawnings took place when the departure from the mean tide range was on the minus side, and only in three cases did they happen when the high water level was greater than 7.7 feet—the average of our spring range of tide (Figs. 10, 11).

It may be suggested, as a criticism of our approach, that the 18-day period, which we took as the average required for the larvae to reach metamorphosis, is too long because, as the summer progresses, the water temperature becomes warmer and the length of the larval period decreases. Such a criticism may be justifiable. However, even if the larval period were shortened to 17, 16, 15 or even 14 days, the assumed dates of the spawning would still coincide in most years with periods other than those of the spring tides. Thus, regardless of the changes in the length of the larval period the results still would suggest that the heavy spawnings took place at widely different lunar phases and correspondingly different tidal conditions.

Discussion

Observations carried on in Long Island Sound during the 13-year period, 1937–1949, showed no definite relationship existing between the major events in the propagation of oysters and the lunar phases. In general, all the important events, such as the beginning of spawning, beginning of setting, dates of heavy spawnings and dates of maximum sets, happened at all four lunar phases and, therefore, under widely different hydrostatic conditions caused by the tidal changes.

The data so far available seem to indicate that spawning of *O. virginica* of our waters is not of the periodic nature, such as that found by Korringa (1947) for *O. edulis* of Holland where "maxima of greater and lesser importance in the extrusion of the eggs occur at spring tides (2 days after full and new moon)." However, in comparing some aspects of the propagation of *O. virginica* with those of *O. edulis* we should again emphasize that we are dealing with two widely different types of oysters, and also with two different complexes of ecological conditions. It is only natural, therefore, that our conclusions should differ from those of Korringa.

Korringa thinks that the rhythmical sequences of the differences in water pressure from the neap to the spring tides, and conversely, exert their influence on the oysters of the Oosterschelde during their breeding period. If comparable differences were not also a regular event in our waters, we could assume that the differences in the spawning behavior of our oysters and those of the Oosterschelde were due to that cause. However, since our vertical tidal movements are also of considerable magnitude, such an explanation is unsatisfactory. In our waters the mean range of tide is 6.6 feet and the spring range is 7.7 feet. On some days, for example, on July 18, 1943, the height of our high water was + 8.7 feet and the low water was − 0.7 feet, thus, the difference between the two tidal levels on that day was 9.4 feet, or over 3 meters. The difference between the high and low water levels for that day at Zierikzee, located at the entrance to the Oosterschelde was, according to Tide Tables of the Atlantic Ocean published by the U. S. Coast and Geodetic Survey, 11.4 feet, or only 2 feet greater than at our station. It is rather doubtful that such a comparatively small difference in tidal range could be responsible for the striking differences in the behavior of the oysters at the two places.

The geographical distribution of *O. virginica* and the range of the tidal conditions under which it exists in nature make it improbable that its spawning is controlled by certain rhythmical changes in the hydrostatic pressure taking place between the neap and spring periods. In general, the natural population of oysters and the extent of the natural oyster beds on our Atlantic coast increase proceeding South. On the other hand, the tidal range decreases from North to South, and in the Gulf of Mexico, where extensive oyster beds exist, the difference between the high and low water levels is often less than 1 foot. Yet, regardless of such small differences between the tidal levels and obviously insignificant rhythmical changes in the hydrostatic pressure, the oysters living in those areas propagate normally.

It is also interesting that, as every experienced investigator has noticed, oysters kept under laboratory conditions in the summer time spawn profusely regardless of the condition of the moon or the stages of the tide in the open water. For example, in our laboratory some spawning oysters may be noticed almost every day during the summer. These oysters, which are kept in shallow trays, are covered with only two to three inches of running water supplied from the storage tank, which is always automatically filled by pumping one hour before high tide. Because the water level over the oysters remains the same, the difference in the hydrostatic pressure cannot be considered as the factor inducing spawning.

It is possible, of course, that, as we have already said, some differences in the spawning behavior of the two species may exist because one of them, *O. virginica,* is oviparous, while the other, *O. edulis,* is larviparous. Furthermore, while the first remains usually of the same sex during the entire spawning period, the second may change its sex several times during the summer. Thus, a comparison of the spawning habits of these two species may be difficult. Because of this consideration one would prefer to compare the behavior of two larviparous species to see whether both are influenced in the same way by the periodic tidal differences associated with certain lunar phases. Such a comparison is possible between *O. edulis* and *O. lurida,* as based on the observations of Hopkins (1937) and Korringa (1947).

As has already been mentioned, Hopkins reported no lunar periodicity in the spawning of *O. lurida.* Its spawning was a continuous process extending for a period of 5 to 6 months. In reference to its intensity Hopkins says "after it once begins, the frequency of spawning slowly increases to a maximum, then gradually diminishes until gravid individuals are found only occasionally." Critical examination of Figure 15 of Hopkins' paper, giving the range of tide and the numbers of "white" larvae (young larvae, just recently developed from eggs) found in 1932, shows that during that season there was only one instance, on May 23, when a large number of larvae occurred during the spring tides. At other periods of the spring tides, about June 8 and 19, and July 7 and 19, young larvae were conspicuously absent. On the other hand, considerable numbers of larvae were often found in samples taken during the neap tide periods. In general, throughout the season, the larvae were more numerous during those periods than during the spring tides. It is apparent, therefore, that Hopkins found no periodic outbursts of spawning confined to the spring tides which follow new and full moon.

It is significant that Hopkins said: "It has frequently been noted that spawning is most likely to begin during or shortly after a period of neap tides." Although this statement does not refer to the maxima in spawning it shows, nevertheless, that such an important event as the beginning of spawning of the oyster population often takes place during lunar periods, which are opposite to those considered necessary to induce profuse spawning in the oysters of Holland. Naturally, it is difficult to conceive that if definite changes in hydrostatic pressure, which are correlated with the lunar phases, are necessary to induce heavy spawnings, an entirely different set of tidal conditions would be needed to cause the first spawning of the season.

We cannot explain the difference in the spawning behavior of *O. lurida* from that of *O. edulis* on the ground that the tidal differences in Puget Sound are considerably smaller than those in the Oosterschelde. On the contrary, they are of greater magnitude. According to Korringa (1947) in the Oosterschelde the tidal range of the spring tides is about 3.9 meters, and of the neap tides, 3.0 meters, the difference being only about 0.9 meters, or less than 3 feet. In the area of Puget Sound, where Hopkins conducted his studies, the range of the spring tides is about 19 feet (6.3 meters) and that of the neap tides, about 10 to 12 feet (3.3 to 4.0 meters). Thus, in Puget Sound the difference between the spring and neap tidal ranges is about 6 feet, approximately twice as much as in the Oosterschelde. Yet, regardless of almost twice as great a range of tide in Puget Sound and of much more pronounced differences in hydrostatic pressure, *O. lurida,* the species so closely related to *O. edulis,* showed no evidence of heavy spawnings at the spring tides, as Korringa reported for the oysters of the Oosterschelde. On the contrary, some of Hopkins' (1937) data suggest that profuse spawning often occurred at the neap tides.

Louis Lambert, General Inspector of the Office of Scientific and Technical Marine Fisheries of France, who recently visited the United States and with whom we discussed periodicity of spawning of *O. edulis* and swarming of its larvae, thinks that so far no such periodicity has been established or observed in the breeding of *O. edulis* along the coast of France. Korringa (1947) in discussing the work of French oyster biologists also found no support for his theory in their work. He believes, however, that the data offered by some of these investigators are not sufficient to decide whether there is a periodicity in the breeding of French oysters.

Thus, so far, periodic heavy spawning of oysters associated with new and full moon, and consequently, with spring tides, has been found only by Korringa for *O. edulis* of the Oosterschelde, Holland. Neither does *O. edulis* of other geographical regions nor the closely related *O. lurida* of Puget Sound show such periodicity. Since Korringa's conclusions are based upon a definite method of collecting field data, it may be desirable to evaluate the merits of his methods.

Korringa's samples were collected from one station at Yersche Bank, which is located in the center of the Oosterschelde basin (Korringa 1947). The larvae were collected by pumping and filtering 100 liters of water through a plankton net. During the most important part of the reproductive season the samples were taken daily, while during the beginning and the latter part of the season they were collected every second day. The collection of samples was usually made at low water slack.

Yersche Bank is located in the southeastern half of the Oosterschelde, which is approximately 17 kilometers long and 10 kilometers wide (Korringa 1941). The Bank itself is at least 7 or 8 kilometers long and approximately 3.5 kilometers wide. The question that naturally arises is how well a single sample taken from such a large area represents the conditions existing there.

The experience of one of us in Long Island Sound and Chesapeake Bay with larvae of *O. virginica,* and in Puget Sound with *O. lurida* would make us hesitate to form a conclusion on the distribution and on the numbers of larvae present in any large body of water on examination of a single sample. Our observations, as those of other American investigators, have shown that larvae, as a rule, are not uniformly distributed even over small areas. While a plankton sample collected at one point may contain a large number of larvae, another sample, taken simultaneously, or a few minutes earlier or later, at another point, only a few feet away from the first one, or at the same point but at a somewhat different depth, may contain none or very few larvae. For example, Nelson and Perkins (1931), studying the vertical distribution of larvae of *O. virginica* in Barnegat Bay, New Jersey, found that the number of larvae varied within one meter's depth from 140 to 35,750 per 50-liter sample. It is obvious, therefore, that no reliable conclusions, as to the numbers of larvae in a large body of water, can be formed on the basis of examination of one or two samples.

Korringa (1941) realized the imperfection of his method because in his discussion of horizontal distribution of larvae in the Oosterschelde in general, and also in the center of Yersche Bank, near which his collection station was located, he stated: "The amplitude of the number of larvae during swarming in the centre itself is a less reliable measure, as it is affected by the degree of proximity of the liberating adults. Thus, the enormous number of larvae (2000 per 50 litres) in a sample collected on the 14th of July 1937 at the station Yersche Bank, for instance, did not point to a heavy swarming, for the diagram (Fig. 8) clearly shows that it must be attributed to the immediate proximity of one (or more) liberating adult(s)." In his article Korringa did not explain when unexpected swarmings should or should not be ascribed to the proximity of liberating adults. Neither did he offer any proof that many maximum swarmings, on which he based his theory of lunar periodicity, cannot be attributed to exactly that cause. However, in a recent personal communication to us he clarifies this point considerably by saying: "Indeed, an objection against my sampling station is that sudden occurrence of young larvae just expelled from mother oyster may cast doubt on the value of a sample. That occurred on the 14th of July and once again in a more recent year. To avoid this difficulty, I always compare 2 samples of the same station, one taken at high tide, one at low tide. Only if those yield approximately the same number of larvae, I dare to adopt the figure for use in spatfall prediction. As a rule the two figures come quite close to each other, though entirely different water masses are encountered in two samples."

In offering a criticism on the inadequate data given by Korringa to support his theory we refer only to the material presented in his 1947 article, which is based on a series of observations made at only one station. There is no doubt that Korringa may be able to offer additional data, based on observations at several other stations situated at various points of Yersche Bank, which will further strengthen his extremely interesting theory.

In conclusion, it should be remembered that the factors inducing spawning of oysters are numerous and their interrelations are extremely complex and, at present, not well understood. Further studies of the physiological conditions of oysters during the pre-spawning and spawning seasons and studies of the influence of the ecological factors on maturation of the gametes should eventually provide the explanation for certain peculiarities in the spawning behavior of different species and genera of oysters.

SUMMARY

1. Observations made during the 13-year period, 1937–1949, showed that spawning of oysters in Long Island Sound began during the last few days of June or during the first days of July. The earliest date of spawning recorded was on June 26, occurring in 1945 and 1949, and the latest, on July 3, in 1937 and 1940.
2. The beginning of the spawning season occurred at all four lunar phases and at widely different tidal conditions.
3. It may be formulated that in Long Island Sound the beginning of spawning of oysters should be expected on June 30 ± 4 days, independently of the lunar phases and of the changes in hydrostatic pressure resulting from the departures from the mean tide range.
4. Daily counts of straight hinge oyster larvae during three seasons showed that there were no definite spawning maxima occurring exclusively within the spring tide periods. On the contrary, the larvae were more numerous during the neap tides.
5. The beginning of oyster setting happened at every moon phase and was not confined or related to definite tidal conditions.
6. It may be provisionally formulated that the beginning of oyster setting in Long Island Sound should usually be expected on July 19 ± 4 days, independently of the lunar phases and of the changes in hydrostatic pressure caused by changes in the tidal levels.
7. In Long Island Sound the time and intensity of setting do not follow a rigid pattern from year to year but, nevertheless, in most instances there are at least two distinct waves of setting with definite maxima or peaks.
8. The peaks of setting vary considerably in magnitude in different years and within the same year.
9. The number of days elapsing between the beginning of spawning and appearance of the first set ranged from 13 to 24 and averaged 18.5 days.
10. The period elapsing between the beginning of spawning and maximum set or peak of the first wave varied from year to year ranging from 16 to 40 days and averaging about 30 days.
11. The beginning of the second wave of setting varied from 47 to 66 days and averaged 56 days after the beginning of spawning.
12. The maximum daily set of the second wave occurred from 57 to 74 days after the beginning of spawning.
13. In general, it was found that in Long Island Sound no definite relationship exists between the important events in the propagation of oysters and the lunar phases. All the events, such as beginning of spawning, beginning of setting and dates of maximum sets, may happen at any of the four lunar phases and, therefore, under widely different hydrostatic conditions.

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On the Use of the Terms *Abundance, Availability* and *Apparent Abundance* in Fishery Biology [1]

JOHN C. MARR

RECENT discussions with several fishery biologists have demonstrated that the terms *abundance, availability* and *apparent abundance* do not have the same meanings to different individuals. Since these terms, or at least the concepts for which they stand, are important ones, the following definitions and remarks are set down with the hope of dispelling rather than adding to the confusion.

The terms may be defined briefly as follows: *Abundance* is the absolute number of individuals in a population. *Availability* is the degree (a percentage) to which a population is accessible to the efforts of a fishery. *Apparent abundance* is the abundance as affected by availability, or the absolute number of fish accessible to a fishery. While abundance is of primary concern, it is most often apparent abundance which is measured. And since the measure (catch per unit-of-effort, for example) for a particular period is often only relative to similar measures for other periods, it should be termed *relative apparent abundance.*

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The abundance of a particular year-class at a particular time is a function of the number of eggs spawned and the subsequent mortality suffered from all causes. That is, obviously,

$$N_{\alpha t} = N_{\alpha o} - M_{\alpha t} \quad \ldots\ldots\ldots\ldots \quad (1)$$

where $N_{\alpha t}$ is the number of individuals in year-class α at time t, $N_{\alpha o}$ is the number of eggs spawned or initial abundance of the year-class at time zero, and $M_{\alpha t}$ is the number of deaths from all causes between time zero and time t. For a population which includes more than one age group or year-class (say n age groups), we may sum over all age groups to get the abundance of the whole population.

$$N_t = \sum_{\alpha = 1 \text{ to } n} (N_{\alpha o} - M_{\alpha t}) \quad \ldots\ldots \quad (2)$$

One important feature of abundance is that it is the sum of all the previous experience, with respect to "births" and deaths, up to time t, of all year-classes in a population at that time. Part of this experience, and perhaps the most important part, may have occurred at a considerable number of months or years before time t. With reference to the determination of N_t, the definition (2) above does not attempt to assign relative importance to initial abundance, fishing mortality and natural mortality. This will no doubt vary between fisheries and even between periods within a single fishery. The assignment of relative importance to one or another of these by the biologist will perhaps be conditioned by the type of fishery with which he is most familiar (i.e., especially pelagic fishery *vs.* bottom fishery).

Works in which estimates of abundance have been based on tagging (or marking) experiments or, much more rarely, on estimates of the total number of eggs produced during a spawning cycle are familiar to all. Indirect estimates of abundance based on the characteristics of the commercial catch have also been developed (see Silliman, 1943, for example).

Availability, which is a percentage or fraction of abundance, may be designated by r. The mechanisms which determine the fraction of a population that is available to a fishery must be rather complex and undoubtedly vary widely between, as well as within species with respect to time and geographical location. These mechanisms may be divided into two kinds: intrinsic ones which are the response of the fish to its environment, and extrinsic ones which are completely independent of the behavior of the fish. Considering first the intrinsic mechanisms, several conditions of r are possible. It may be constant and be zero, or 1.0, or some intermediate value. If it were zero, no fish would be available and if it were 1.0, the entire population would be available. One can imagine a small stream from which it would be possible to catch every ascending fish, with gear located in the stream. One can further imagine that this stream has a fall run of salmon which are fished only while in the stream. In the spring, or at any time before the run started, availability would be zero and no fish could be caught. During the course of the run the entire population could be caught and, considering the entire period of the run, the availability would be 1.0. If only a constant percentage of the population, say 5 percent, entered the stream each day, the daily availability would be constant and would be 0.05.

Probably a more common situation is one in which r is not constant, but varies in response to varying environmental conditions. An example may be present in the Oregon-Washington pilchard fishery, where a negative correlation between the catch per unit-of-effort for each of nine seasons and the average monthly air temperatures during the season has been demonstrated (Marr, 1950). A special case of this type of varying availability is found in fisheries in which the youngest age groups are not as available to the fishery as are the older age groups. Such young age groups are often spoken of as being not fully recruited into the fishery.

For some species, availability may be constant (and be zero, 1.0, or some intermediate value) at some times and variable at others. The sei whale fishery off the Norwegian Coast (Hjort and Ruud, 1929) is an example. No sei whales are taken in that region before the rapid spring increase in the total stock of the copepod *Calanus finmarchicus*. At this time r is constant and zero. At the time of rapid increase in numbers of copepods, the catch of sei whales parallels copepod abundance, with a slight time lag; the availability is then variable.

These and similar examples do not, of course, explain what is happening any more than the recapture of a marked salmon in its parent stream explains the homing instinct.

There are several kinds of extrinsic factors that can affect availability. Perhaps the most common is the weather. All fisheries suffer periods when unfavorable weather conditions seriously hinder or completely prevent fishing. The catch is lowered by the inability of the fishermen to go to sea and operate their gear, not by reduced abundance or any unfavorable behavior of the fish. Of course, as indicated above, weather may also have an influence on fish behavior.

In trawl fisheries bottom topography must be an important factor. It is easy to imagine two banks of equal area with equal numbers of flounder distributed evenly over each bank. One bank is relatively smooth and trawls can be operated with full efficiency over the entire bank. For the fish on this bank r would be 1.0. The other bank is relatively smooth over one-half of its area, while the other half is so rough and irregular that it is impossible to drag a trawl over it. For this bank r would be 0.5.

Finally, availability may be more complicated than any of the examples given would indicate. It may be determined by the simultaneous operation of a complex of factors, rather than by a single factor. Or it may be determined by one complex of factors over a certain range of their values and, outside that range, be controlled by a different complex of factors.

In general, availability is not well understood for most fisheries and, in fact, a great proportion of the processes involved still remain to be recognized and analyzed. Variations in availability in time and space, and even with respect to different age groups within a population at a single place and time, or with respect to population size, are little known. However, for fisheries that are pursued over the entire range of the species involved, it might be expected that variations in availability would generally be less important than variations in abundance in determining the yield (ignoring, for the present, fluctuations in fishing intensity). For fisheries that are carried out over only a portion of the range of the species involved (as, for example, over part of a migratory route), it might be expected that variations in availability would often be more important than variations in abundance in determining the yield. (In actual practice, it will often be necessary to work with catch data and to deal with relative availability rather than with absolute availability. Under certain conditions it will ordinarily be impossible to distinguish between a change in availability and a change in rate of natural mortality. The collective effects of these two factors may be termed *accessibility.*)

In contrast to abundance, which, in general, is determined by events spread over a considerable period of time, availability may bear a much closer temporal relationship to the processes determining it. Indeed, the processes and the results may often be simultaneous, for all practical purposes.

It should be clear that the size of the available population upon which a fishery operates will be rN_t, the apparent abundance. All methods of estimating abundance, N_t, which are based in one way or another upon original catch data, will actually be estimating apparent abundance. As r approaches unity the estimate of apparent abundance will, of course, approach the true abundance.

The most common estimates of apparent abundance are relative and are measures of catch per unit-of-effort. However these may be derived, they are in effect equivalent to the total catch divided by the total effort, $\frac{C}{f}$, for the time interval selected. Workers developing measures of relative apparent abundance frequently assume, tacitly or explicitly, either that r is unimportant or that it is constant. There is the further assumption, more frequently tacit than explicit, that a measure of relative apparent abundance is some constant proportion of abundance. That is, that (including availability)

$$\frac{C}{f} = krN_t \qquad (3)$$

where k is some constant.

If the relationship in (3) above obtains, and assuming for the moment that r is unity or some constant percentage, Ricker (1940) and others have pointed out that the definition of N_t will have to be qualified or modified according to the period of time over which the catch per unit-of-effort is calculated. For example, $\frac{C}{f}$ for a season of several months duration would be proportional to the average abundance over the entire season, rather than to the abundance at the beginning of the season. It will, of course, also be proportional to the abundance at some particular instant during the season, but this particular instant generally will not be known. This is of parenthetical interest here, since it affects the application of the concepts, rather than the concepts themselves. (Such application should also include consideration of factors such as the intensity of the fishery, competition between effort units, etc., which are not included in this discussion).

Ricker (1940) has commented at some length on the relationship between catch per unit-of-effort and abundance (or, more properly, apparent abundance). A clear understanding of the relationship is essential and reference should be made to that work, since it is my intention only to define and to suggest terminology concerning concepts which need to be clarified. Clarification is needed because of the use of the same term for different concepts and because of confusion caused by tacit assumptions. A few examples, chosen more or less at random, will demonstrate the non-uniformity of application of these terms. Quite commonly the terms used are not defined and it is therefore up to the reader to decide from the context exactly what the writer meant. Thus, misunderstandings may readily arise.

Pearson (1948), referring to the blue-crab fishery of Chesapeake Bay, has regarded catch per unit-of-effort as an index of abundance; that is, that catch per unit-of-effort is proportional to abundance. This is the equivalent of relative apparent abundance as defined above and tacitly assumes that r is constant. He recognized availability and used that term without explicitly defining it. His use of it is sometimes in the sense that it is defined above and sometimes in the sense of relative apparent abundance.

This example represents perhaps the most common usage; catch per unit-of-effort regarded as proportional to abundance, either with or without recognition of availability. There is, however, considerable variation in terminology. Schuck (1949), in his study of the New England haddock fishery, used "relative size of the population" as an equivalent to my "relative apparent abundance." He used availability in the sense that it is used here, but did not define it. Some of the European workers, Strubberg (1939) for example, referred to catch per unit-of-effort as a measure of the density of the stock. Again, the implication is that catch per unit-of-effort is proportional to abundance. Fry (1949: 38), in a lake trout fishery study, used "The yield per effort . . . or availability . . ." This is evidently the equivalent of relative apparent abundance. His use of "catchability" may correspond to my use of "availability." Similarly, Needler (1948: 166), in a general discussion, stated that catch per unit-of-effort ". . . is practically synonymous with availability or the ease with which fish can be obtained."

Sette (1943: 5), in his discussion of a fisheries research program, gave this definition: "At uniform availability and with no competition between units of gear: Relative abundance = catch-per-unit-of-effort. . . ." This is essentially the same as the definitions offered here. Sette (1949) has used apparent abundance and availability as defined above and I have previously so used these terms (Marr, 1950).

These examples certainly indicate the non-uniformity of terminology, and also show that a clear understanding of the underlying concepts is not always held. It is obviously essential that empirical data be associated in the investigator's mind with the appropriate concept. It may, in fact, be desirable to reserve the terminology suggested here for use in denoting these concepts only. In the following tabulation are listed the concepts and their empirical equivalents.

Concept	Empirical data from which values may be estimated
Abundance	Estimates based on tagging or marking experiments, assuming r to be constant and unity, or, when r is variable and less than unity if the value of r is known; estimates based on number of eggs produced during annual spawning cycle (applies only to abundance of spawning population); direct enumeration (such as weir counts).
Availability	Variations in catch not associated with abundance or fishing intensity, but rather with variations in environmental factors.
Apparent abundance	Estimates based on tagging experiments with r variable.
Relative apparent abundance	Catch per unit-of-effort data.

In summary, *abundance, availability* and *apparent abundance* denote three important and distinct concepts in fishery biology. Confusion has arisen owing to the non-recognition of one or more of these concepts, to the wide range of terms used to represent the same concept, or to the use of the same term for different concepts. While the terms used here seem reasonably apt, they are not those in widest use and perhaps more appropriate ones could be suggested. However, standardization would not be essential if workers would define their terms adequately.

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s the Pacific Sardine Disappearing?

J. L. McHUGH* and ELBERT H. AHLSTROM†

The senior author, a native of British Columbia, completed his doctoral research in 1950 at the Scripps Institution, where he has most recently been associated with the investigation of the sardine, a part of the Marine Life Research program. Previously he was a scientific assistant of the Fisheries Research Board of Canada until he was called into military service. In January 1951 he became director of the Virginia Fisheries Laboratory. Dr. Ahlstrom (Ph.D., Ohio State, 1934) has been with the Fish and Wildlife Service since 1939, and is now in charge of the recruitment research on the California sardine. He is concerned also with the identification of the fish larvae occurring off the west coast of North America and has been successful in tracing a number of complicated life histories.

EACHING a maximum of almost 800,000
tons in the season of 1936–37 and remaining above the half-million-ton level during
ensuing eight seasons, the annual catch of sar-
s along the Pacific coast of North America
ned abruptly in the years following 1945. So
p was this drop that by 1947–48 the total
ings only slightly exceeded 100,000 tons.
med by the disaster that appeared to be
tening this major California industry, which
esses about 90 per cent of the total Pacific
sardine catch, the fishery operators began to
nd the research being conducted.

uch valuable research on the sardine had been
and was in progress at the time of the
ne, but the work was hampered by a lack of
uate funds and facilities. Both scientists and
tors felt the need of expanding the research
a, especially in the oceanographic field.

ring the spring of 1946 the San Francisco
ne Association allotted $30,000 for an inves-
on of availability of sardines off San Fran-
The purse seine vessel *Pearl Harbor*,
pped with echo-ranging gear as an aid in lo-
g sardine schools, made a number of cruises
entral California. Scientists of the California
ion of Fish and Game and the U. S. Fish and
life Service who participated in these cruises
observations on temperature and plankton distribution. Only limited information was secured on sardine availability, but the industry was impressed with the value of oceanographic fisheries research, notwithstanding its high cost.

To provide additional research funds the California sardine operators in 1947 voluntarily proposed a levy of 50 cents per ton on sardine landings, in addition to a similar tax then in effect. A Marine Research Committee, consisting of nine members representing the industry, scientists, and the people of California, was set up to administer the new funds. This body was largely responsible for securing from the California legislature a grant of $300,000 (later about $400,000) annually to the University of California for marine life research, with particular emphasis on the analysis of oceanographic conditions that may determine the productivity of the ocean waters.

The augmented sardine research program is a unique cooperative venture in oceanography and fisheries biology. Major contributions are being made by the Bureau of Marine Fisheries of the California Division of Fish and Game, the South Pacific Fishery Investigations of the U. S. Fish and Wildlife Service, and the Scripps Institution of Oceanography of the University of California. In addition, the California Academy of Sciences is studying sardine behavior.

The work at sea, which forms so important a part of the expanded program, requires a fleet of vessels capable of cruising the open Pacific and carrying out their duties under almost all weather conditions. For this purpose, four ships are en-

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Vildlife Service.

FIG. 1. The *Yellowfin,* research vessel of the Bureau of Marine Fisheries, California Division of Fish and Game, engaged mostly on studies of the Pacific sardine.

gaged exclusively in the collection of data. These are the *Yellowfin* (Fig. 1), a 114-foot, wooden-hulled ex-Army freight and supply ship, of the California Division of Fish and Game; the *Black Douglas* (Fig. 2), a 133-foot, steel-hulled ex-schooner, of the U. S. Fish and Wildlife Service; and two ex-Navy vessels, of the Scripps Institution (Fig. 3), the *Crest,* a wooden-hulled 136-foot minesweeper, and the *Horizon,* a steel-hulled, 143-foot tug.

Periodic cruises with three of these vessels are made throughout the year over an area extending from Oregon to central Lower California and to a distance of approximately 400 miles offshore. Each ship is at sea for a period of about two weeks in every month, occupying a series of 40–50 oceanographic stations (Fig. 4). At these stations, from observations of temperatures and salinities at 15 depths from the surface to 1,000 meters (Fig. 5), the course and velocity of the oceanic currents are estimated. Samples of water collected from each depth are analyzed for dissolved oxygen and phosphate content. Hauls with fine-meshed nets (Fig. 6) are made to determine the kinds, abundance, and distribution of small organisms, including fish eggs and larvae. Material is also collected for determination of the amount of microscopic plant life.

Previous Investigations

The Bureau of Marine Fisheries of the California Division of Fish and Game has been investigating the resource for nearly a third of a century. Within this period this agency has followed its growth from its beginning as a major fishery during the first world war, through its period of rather uniform expansion until 1936–37, through the years of seeming stability, to the recent epoch of reduced abundance. As a result, this is o
the better-documented fisheries in the world.

The changes in the sardine population bro
about by a rapidly increasing fishing pressure
been observed since 1918. It was apparent fo
ing the 1934–35 season that the catch per
of-effort was decreasing, even though the
catch continued to rise and maintained a
level for ten years (Fig. 7). Despite imp
ments in vessels and gear, which greatly incre
the efficiency of exploitation, greater effort
being expended to catch equivalent amoun
fish.

The California Division of Fish and Game
made many other important contributions.
to 1938 its scientists investigated sardine sp
ing over much of its range off California and
off Lower California, and established that
area off southern California was an impo
spawning center. In cooperation with agenci
British Columbia and in the states of Washin
and Oregon, they conducted a tagging prog
which showed that individuals move from sout
and central California to British Columbia
from the latter region to California. It was
cluded from these and other studies that the fi
ies from British Columbia to southern Califo
and even as far south as central Lower Califo
were exploiting the same stocks of fish.

In 1938 the U. S. Fish and Wildlife Servic
up the South Pacific Fishery Investigations,
headquarters at Stanford University, for the
pose of augmenting research on this rapidly g
ing fishery. This group focused its attentio
the problem of age determination in sardines
on the success of recruitment in relation to o
ographic conditions. Criteria were develope
which the annual marks on scales and ot

FIG. 2. The *Black Douglas,* research vessel of the
Pacific Fishery Investigations, U. S. Fish and W
Service, employed in recruitment and oceanograph
search of the Cooperative Sardine Research Pro

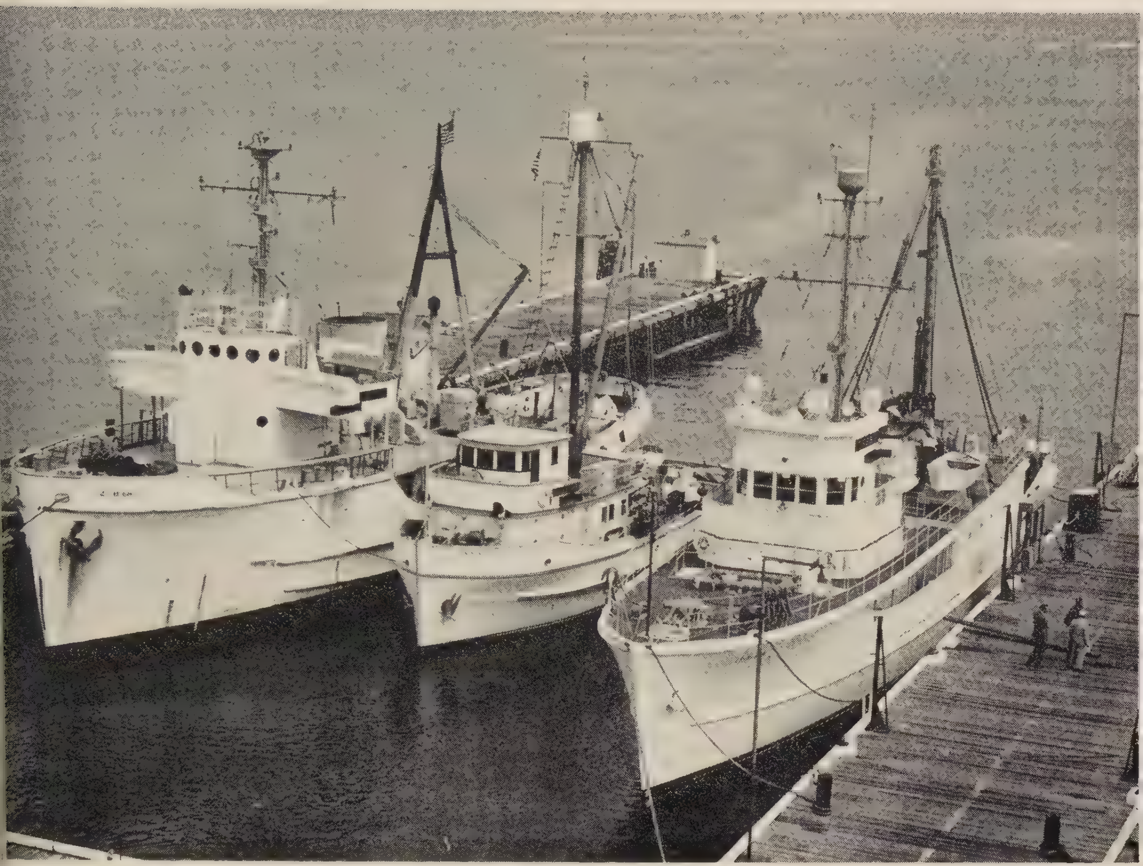


FIG. 3. The *Horizon,* left, and *Crest,* right, of the Scripps Institution of Oceanography, University of California, part in the oceanographic and recruitment studies of the Cooperative Sardine Research Program. The *Paolina* nter, has also been used in certain phases of the program.

be recognized, and thus the age composition e catch determined rather accurately. The of the age composition of the commercial soon developed into a cooperative project een the U. S. Fish and Wildlife Service and California Division of Fish and Game and is being carried on routinely, with the assistance itish Columbia and the states of Washington Oregon. Undertaken as a cooperative program the Scripps Institution of Oceanography, ecruitment study foreshadowed on a modest the research that forms so important a part of urrent expanded program. Such cooperation cterizes much of the Pacific sardine research.

Cause and Effect

st of the fish in the commercial sardine catch om one to five years old. During the period 1941, covered by routine age analysis, only 4 per cent of the fish have been six years or older. The age composition of the catch lifornia waters changes with the season, the hery taking mainly young fish and the average age increasing as the fishing season progresses. The average age of fish taken in the several fishing ports also increases from San Pedro to British Columbia. In the Pacific Northwest, fish have been available in quantity only during the summer months, whereas off California sardines are taken commercially from August through February. These facts have been interpreted as indicating that the fish move northward each summer and return in the fall and winter, the older fish reaching higher latitudes. The seasonal changes have not been as marked in recent years as formerly, mainly because the proportion of older fish in the population has been considerably reduced (Fig. 8). Before the recent decrease in landings, about 60 per cent of the catch in numbers was made up of fish three or more years of age, but since 1946 these ages have contributed only about 33 per cent of the total. In California waters fish of one or two years of age have become the chief support of the fishery, whereas in the Northwest the change in age composition in conjunction with a decline in abundance has led to the collapse of the fishery.

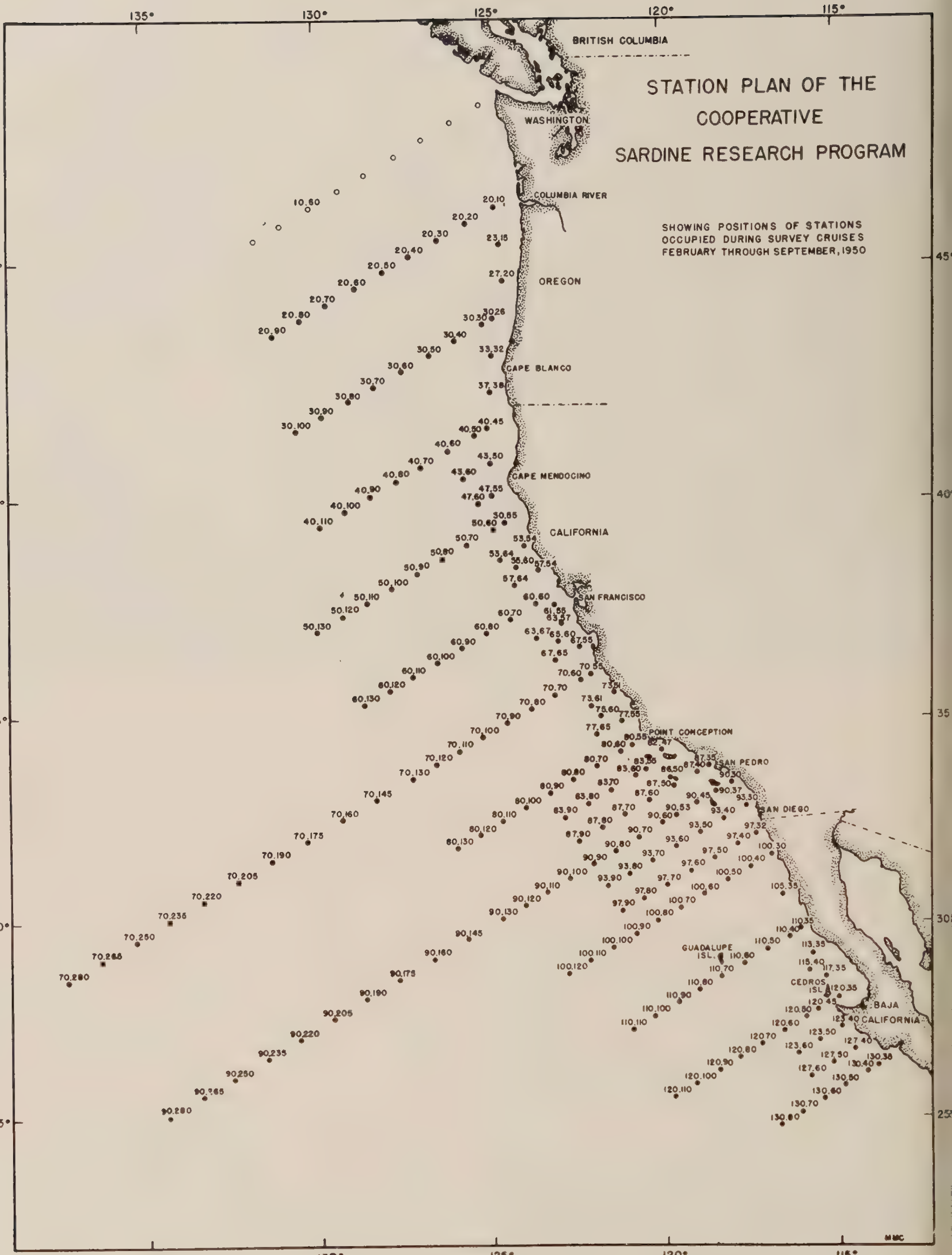
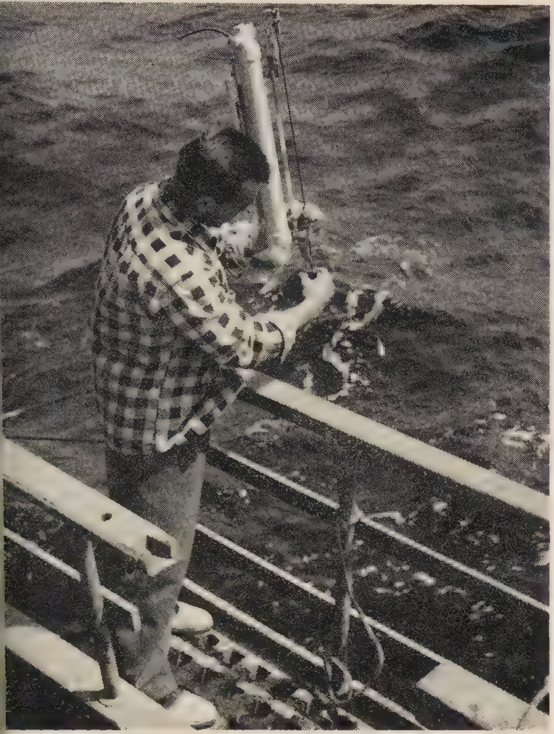


Fig. 4. Pattern of hydrographic stations off the west coast of North America. Most of the stations shown occupied at monthly intervals by the vessels of the Cooperative Sardine Research Program.



IG. 5. Nansen bottle attached to the wire preparatory naking a hydrographic cast. A series of 15 such bottles ised at each station to measure temperature and to ect water samples for determining salinity, oxygen, phosphate content at appropriate depths from the ace to 1,200 meters.

s pointed out previously, the Pacific coast sar-e fishery has passed through three phases: a nty-year period of rapid growth, a decade of ly constant yield at a high level, and a sudden alarming decline amounting almost to collapse ll fishing ports except San Pedro. That the k season of 1936–37 was followed by a succes- of fruitful years of fishing was due largely to a ession of good spawning seasons, climaxed by influx of an unusually large year class spawned 939. Had it not been for these successful year ses, the collapse might have come much sooner. the other hand, continued spawning success ht have considerably delayed the collapse or ented it entirely. In addition, the decline in lings was accentuated by poor survival of the lt fish, or by a change in availability.

is characteristic of pelagic-spawning species as the sardine that the survival of young from ason's spawning varies greatly from year to . Those that survive in a very favorable year ribute many more times the number of fish to commercial catch than do the recruits from a year. During the early years of the fishery e variations in recruitment, although recognized by the biologists, were hardly obvious to the fishermen, because the fluctuations were hidden by the presence of relatively large stocks of older fish. Concurrently with increased fishing pressure—and in the opinion of many because of this pressure—this buffer was effectively reduced.

If the causes underlying the variations in survival of recruits from year to year can be detected, the success of each year class may be determined a year or two in advance of its entry into the fishery. The value of such information to the industry is recognized. The hope that such predictions could be made was a dominant factor in prompting the industry and the legislature to provide funds for expanding the research.

Objective of the Expanded Program

The main objective of the expanded sardine research program is to understand the sardine in relation to its physical and chemical environment, its food supply, its predators, and its competitors, and to evaluate such findings in terms of the survival of young and in terms of the distribution and availability of the sardines when they reach commercial size.

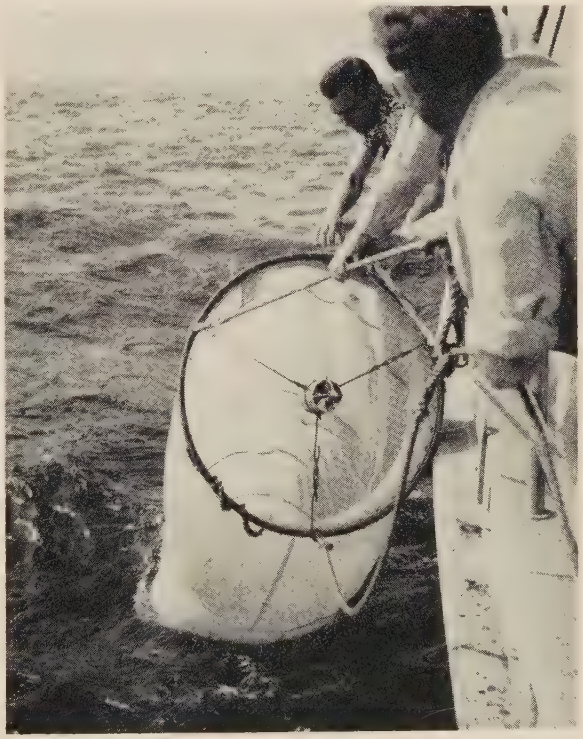


Fig. 6. Bringing the plankton net on board at completion of a haul. These nets, of fine-meshed silk, are provided with a meter in the mouth to measure the amount of water strained. They capture eggs and larvae of the sardine and of many other fish, in addition to providing a sample of the small organisms on which the sardine feeds.

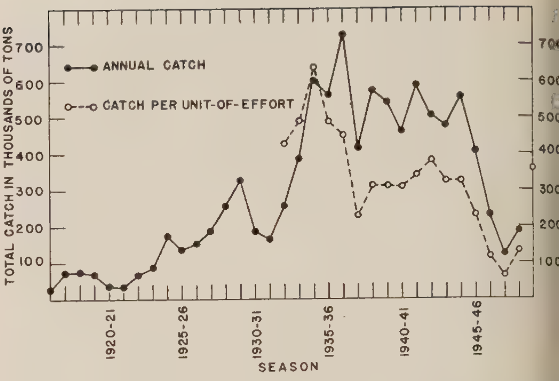


Fig. 7. Annual sardine landings in thousands of to for the entire Pacific coast, illustrating the early expa sion and recent decline of the fishery. The average cat per unit-of-effort is shown from 1933 to date.

Environmental relationships. Fluctuations in the sardine supply cannot be understood clearly without considering the interrelationships between the species and the physical, chemical, and biological conditions under which it lives. It is the task of the physical oceanographers in the program to provide data that will lead to a better understanding of the oceanic circulation off the Pacific coast of North America. Of particular importance is the necessity of measuring and recording seasonal and annual fluctuations in the horizontal and vertical circulation patterns. Both types of circulation may have significant effects on the distribution, survival, and availability of young and adult fish. The factors that control the vertical circulation are of particular interest in that they provide the mechanism by which the nutrient-rich subsurface waters, characterized by low temperature and high salinity, upwell into and fertilize the upper layers where plant growth takes place. Marine plants, the basic food producers of the sea, are confined to a surface layer seldom deeper than 300 feet, the depth of effective light penetration. The plants utilize certain essential chemical raw materials, such as nitrates and phosphates, that must be replenished constantly, or productivity will be low. It is now known that the duration and intensity of upwelling vary considerably from year to year and from place to place. An understanding of these variations may provide a clue to the distribution and success of year classes of sardines.

Survival and recruitment. Much of the research being conducted cooperatively by the Scripps Institution and the Fish and Wildlife Service is directed toward determining the causes underlying the success or failure of year broods of sardines. It is well established that survival varies considerably from year to year, for there appears to be no very consistent relation between the size of the spawning population and the number of recruits that it provides for the commercial fishery. The factors that effectively influence the survival of a year's brood of young are diverse and complicated. On hatching, the young sardine carries with it from the egg a supply of yolk that lasts only a few days. Before this food supply is exhausted, the tiny threadlike larvae, not much more than a sixth of an inch long, require, lest they perish, a supply of suitable food near at hand. This food must be small and must be present in quantity in the right place and at the right time, for the larvae have small mouths and are not active swimmers (Fig. 9). During the larval period they are subject to predation and competition from many sources, and perhaps also to epidemic disease. It it presumed that during these early stages the greatest mortaliti occur.

There is some evidence that the area of spawning may vary considerably from year to year a that these annual variations have a bearing on t success of spawning. Although a large proporti of the eggs are deposited in two major regions o the coasts of southern California and central Lowe California, in certain years highly successf spawnings may take place elsewhere. In the ear summer of 1939, for example, unusual numbe of nearly ripe sardines were taken in the fisher off Washington, and in the spring and summe of 1940 tremendous concentrations of young sa dines of the large 1939 year class were observe in the waters of British Columbia and Washingto It is possible that young of this year brood we more abundant in the waters of the Pacific Northwest than in the usual nursery grounds off southern and Lower California. The success of th 1939 year class may, therefore, have resulted fro an unusually wide distribution of spawning. Ur der such conditions the chances for survival c young fish should be greatly increased, for a muc greater bulk of food would be available over th larger spawning area, and the chances would b greater that some groups of larvae would e counter particularly favorable conditions.

In order that the population be maintained at constant level of abundance, only two recrui resulting from the spawning of each female nee survive to spawning age. A female sardine spaw about 100,000 eggs per season, and her total pr duction may amount to several hundred thousan eggs. Assuming that the number of eggs produce by a female during her life span is 200,000 and th two fish resulting from her spawning reached commercial size, the resulting mortality from egg

It would be 99.999 per cent. If survival were eased 100 per cent, thus doubling the popula- , the total mortality would be reduced by only 1 per cent. In this connection it is possible that oceanographic studies will provide informa- on variations in currents and in the physical chemical properties of the ocean waters that be correlated with the varying production of ines.

he problem of availability. Adult sardines are e available to the fishery during some years in others. This source of fluctuation in the mercial catch is being investigated by the fornia Division of Fish and Game. The prob- is basically one of sardine distribution in rela- to physical, chemical, and biological oceano- hic conditions. Schools located by echo-ranging echo-sounding are sampled to determine the and age-composition of the species present. In tion, oceanographic observations are made and kton hauls taken for comparison with the ach contents of the fish. These observations to the larger framework of the cooperative re- h at sea.

edicting the strength of year classes. The gth of a year class probably can be measured ny stage following larval development, al- gh not with equal facility during the younger s. In the past a reliable measure has been pos- only after the year class has entered the com- ial fishery. Since this method has limited ictive value, it is important that estimates be in advance of recruitment into the commer- tocks. The problem is being given considerable tion in the research program. Two methods of ating the abundance of young sardines are investigated. The first, employing quantita- plankton-collecting procedures, will provide a ure of abundance and mortality during the early stages when the young fish are randomly distributed. The second, based on surveys on the nursery grounds, will provide an estimate of relative abundance of schooling young four to six months old. Several other lines of investigation may provide data for forecasting the strength of year classes. Physical and chemical observations may be found to fit patterns that vary in the same way as year-class strength. For example, there may be a direct correlation between intensity of upwelling and year-class strength, for which presumptive evidence has been found in the annual variation of salinities off the coast.

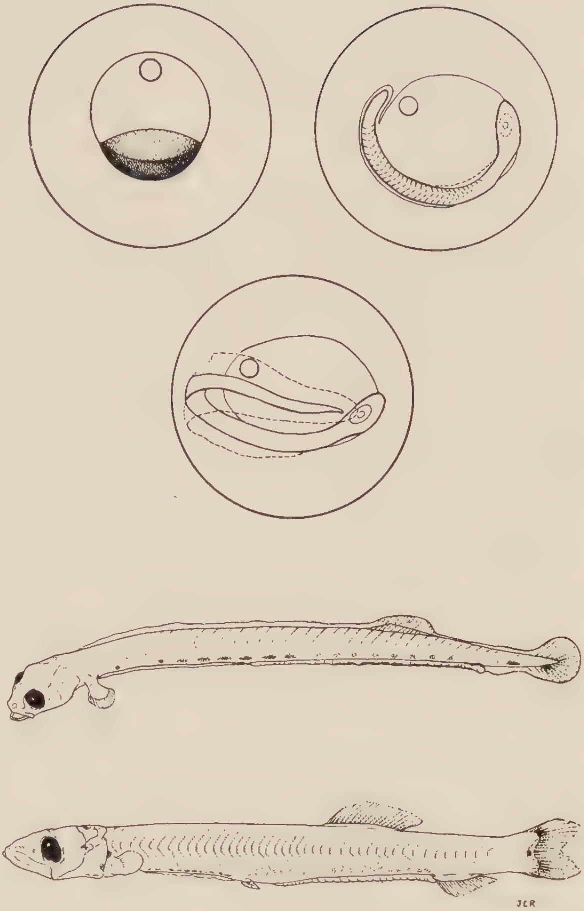
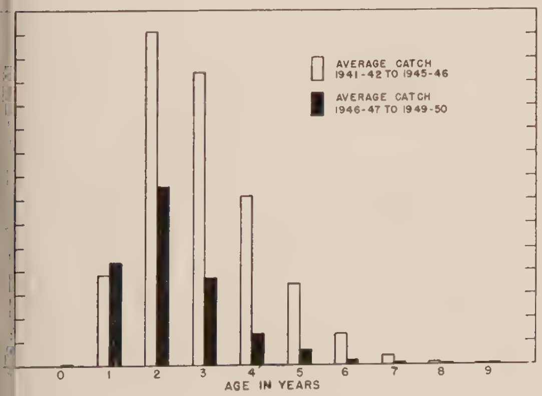


FIG. 9. Stages in the development of the egg and the larva of the Pacific sardine. The egg is approximately 1.7 millimeters in diameter. The two larval stages are about 10 and 25 millimeters long, respectively.



8. Age composition of the sardine catch before ter the recent decline in sardine abundance.

Recent Developments

Some important results have already been obtained. It has been confirmed that sardine spawning takes place in water of rather specific temperatures, almost entirely within the narrow limits 13°–16° C. The importance of the southern California region as a spawning area has been reemphasized, and further information has been gained on a second region of possibly even greater importance, lying to the south of Cedros Island off Lower California.

The surveys are yielding valuable information on the distribution, abundance, and life history of many species of fish. Much of this information should be of value to the sardine industry in indicating latent marine resources capable of being exploited in the lean years. Since there is a limit to the total amount of protein food that the ocean can produce, decrease in abundance of one species may be accompanied by proportional increases in others. If this be so, we cannot take full advantage of our fishery resource as long as we exploit only a part of it by concentrating on certain species. Consequently, the fuller utilization of such underexploited fishes as anchovy, saury, and jack mackerel should be encouraged. Major expansion of these fisheries should be accompanied by adequate biological studies. The information being gathered in the present surveys would be of considerable value in planning the research program and would contribute to the solution of the problems involved.

A development that will have far-reaching implications in oceanographic fisheries research has been made in the estimation of ocean currents. A method has recently been perfected by means of which the effect of rhythmic variations in density, apparently associated with tide-producing forces, may be eliminated from the determinations. Charts of current patterns, formerly characterized complicated series of eddies, thereby have be considerably simplified.

The requirements of the cooperative progra have stimulated the development of many new a improved types of oceanographic equipment. Ou standing is the high-speed plankton sampler, a d vice that can be operated at top cruising speed, a that gives a continuous record of both depth a the amount of water strained. To carry this instr ment down and to maintain the desired depth especially designed bronze depressor is employe These and other developments have excited co siderable interest among scientists in many fields

The Pacific sardine is not disappearing. Fi populations, whether exploited commercially not, are subject to rather wide fluctuations abundance. The decline in sardine abundan seems to have been due to a succession of pe spawning seasons coincident with a change in t availability or an increase in the natural mortali of adults. The European pilchard and the Japane sardine fisheries have suffered similar declines abundance. The catch of Pacific sardines duri the current fishing season may reach 350,000 to indicating that a substantial recovery is taki place.

Illustrations: Fig. 1, Leo Pinkas; Fig. 2, Orthe L. Wallis; Figs. 3, 5, and 6, John MacFall; Figs. 4, and 8, drawn by Margaret Calderwood; Fig. 9, drawn Janet Roemhild.

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AN AQUARIUM EXPERIMENT ON THE AMERICAN EEL AS A PREDATOR ON LARVAL LAMPREYS.—The parasitic sea lamprey, *Petromyzon marinus,* has in recent years spread throughout Lakes Huron and Michigan and is now firmly established in these waters (Applegate, 1949, Mich. Cons., 18 (4): 13–15). Coincident with their spread, the abundance of lake trout, *Salvelinus namaycush,* has declined in both lakes (Hile, 1949, Trans. Amer. Fish. Soc., 76 (1946): 121–147)[1] and the lake trout as well as other species of fishes are showing an increase in scarring from lamprey attacks. For Lake Michigan the analysis of fishermen's questionnaires gave an increase in percentage by weight of lamprey-scarred lake trout from 31 percent in 1947 to 41 percent in 1948. The sea lamprey is now spreading through Lake Superior, the last of the Great Lakes containing a large population of lake trout.

Various methods to reduce the lamprey populations have been considered and are being tested. Among these is the possible introduction of a predatory species. From field observations along our Atlantic Coast the author regards the American eel, *Anguilla rostrata* (LeSueur), as a potential predator of the lamprey. In coastal streams and estuaries this fish is commonly found on muddy bottoms into which it burrows with ease. The eel generally spends its daylight hours buried in the mud with only its snout protruding, leaving its burrow most often at dark to feed. In feeding, the eel explores openings and crevices, and roots through the mud for its prey. The ammocoete of the sea lamprey also digs into the mud, but feeds by protruding its head slightly from its burrow and sifting the small organisms from the thin layer of water adjacent to the mud. Aquarium observations show that the eel is the more efficient burrower. In an aquarium having a coarse sand bottom the eel could bury itself immediately while the ammocoete struggled for some time before gaining entry. The possibility was therefore entertained that feeding eels attracted by the movement of the ammocoete would follow them into the mud and kill them.

In an experiment to test this hypothesis 4 inches of mud taken from typical ammocoete beds was placed in each of two identical aquaria of 45-gallon capacity. The mud was carefully searched for ammocoetes, and was free of them. On September 1, 1949, twenty-two ammocoetes of the American brook lamprey, *Entosphenus lamottei,* of the size ranges shown in Table I, were placed in each aquarium. The ammocoetes were anesthetized with ether before they were measured. Air was bubbled through both tanks and there was a slight circulation of water. Three eels, 219, 242, and 281 millimeters long, were placed in Tank 1 on September 2, 1949. Tightly fitting screens covered the tanks.

On September 20, a 165-millimeter ammocoete was found dead on the surface of the mud in Tank 1. Close examination showed a distinct notch located about 15 millimeters from the posterior end of the body. It has been noticed in aquaria that when the eel attempts to eat food too large to swallow, it seizes the food firmly and then vigorously rotates its body about its long axis in an effort to tear the food into smaller pieces. It is possible that the notch on the lamprey's body could be explained by this action. On September 23, a 150-millimeter ammocoete was found dead on the surface of the mud in Tank 1. Several places on the body were badly squeezed and showed large blood clots. These injuries could have been caused by the eel's mouthing the ammocoete. On September 23, three weeks after the introduction of the ammocoetes into the tanks, a count was made of the numbers remaining in each tank. The mud was carefully examined twice, a little at a time, in white enamel pans and all the ammocoetes removed. In Tank 1, containing the eels, 16 ammocoetes were recovered. In Tank 2, the control, which contained no eels, 21 ammocoetes were recovered. The mud was returned to each tank and the 16 remaining ammocoetes placed in Tank 1 together with the three eels, and the 21 remaining ammocoetes in Tank 2 under the same conditions as before.

On October 7, the 219-millimeter eel was observed outside its burrow nosing along the bottom. Suddenly a puff of dirt rose from one of the lamprey burrows. The eel quickly moved to this hole, searched it with its snout, and then rapidly burrowed in. Whether or not it caught the ammocoete is unknown, but there is strong indication that any slight activity of the larval lamprey will attract nearby eels. The experiment continued until October 14, 1949, six weeks after its initiation. During the entire experimental period no food was provided the eels other than the worms, insect larvae, and ammocoetes contained in the mud. At this time the aquaria were emptied and the mud examined as before. In Tank 1, containing the eels, only three ammocoetes were found. In Tank 2, without eels, 21 ammocoetes remained.

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[1] For Lake Huron only. The same condition is shown in unpublished data for Lake Michigan.

Undoubtedly the eels had destroyed a considerable number of the larval brook lampreys. How effective the eel will prove as a predator on the larval sea lamprey in nature is a matter for large-scale experimentation under natural conditions.

Factors that favor the use of the eel as a tool in reducing the populations of larval lampreys are: (1) eels may be caught readily in large quantities at a reasonable cost along our Atlantic Coast; (2) they are hardy fish and if kept moist can be transported great distances without water; (3) they will not reproduce in fresh water and therefore cannot be a permanent danger to the biological equilibrium of the Great Lakes; (4) they may possibly distribute themselves over a watershed containing lamprey larvae and thus eliminate the expense of individual attention to each of the larval beds; (5) they will be an active control factor for as many years as they live; and (6) the adult eel can be utilized as a food and game fish.

TABLE I

LENGTH FREQUENCY OF AMMOCOETES OF THE AMERICAN BROOK LAMPREY, USED IN AQUARIUM EXPERIMENTS TO TEST PREDATION BY THE EEL

Length of ammocoetes (millimeters)	Number of ammocoetes	
	Tank 1*	Tank 2†
30–39	1	1
40–49	1	1
50–59	.....	.....
60–69	1	.....
70–79	.....	1
80–89	1	1
90–99	1	2
100–109	4	3
110–119	.....	1
120–129	3	2
130–139	2	4
140–149	5	3
150–159	2	3
160–169	1	....
Total	22	22

* Contained three eels, 219, 242, 281 mm. long.

† Control tank, no eels present.

Against the use of the eel is its possible predation upon other species of fishes. In the older, descriptive literature (Cheney, 1899, N. Y. Fish, Game and For. Comm. Rept. for 1898: 279–288; Jordan, 1905, A Guide to the Study of Fishes, 2: 147) the eel has been given a bad reputation as a fish predator. However, records of analyses of stomach contents in more recent literature (Bishop, 1936, Suppl. 25th Ann. Rept. N. Y. Cons. Dept. (1935): 122–139; Hartley, 1940, Freshwater Biol. Assoc. Br. Emp., Sci. Publ. No. 3; and Frost, 1945, *Ibid.*, 13th Ann. Rept.:9–13) indicate that the eel is omnivorous and that fish do not play as important a part in its diet as was formerly thought. The effect on other fishes should be thoroughly tested under natural conditions.

The Institute for Fisheries Research, Michigan Department of Conservation, provided space and other facilities for the conduct of this experiment. Staff members of the Institute supplied equipment for, and aided in, the collection of the ammocoetes of the brook lamprey.—ALFRED PERLMUTTER, *New York State Conservation Department, 65 W. Sunrise Highway, Freeport, L. I., New York.*

Reprinted from COPEIA, 1951, No. 1, March 21

THE POSITIONAL PATTERN OF THE COPEPOD PARASITE *SPHYRION LUMPI* ON THE ROSEFISH, *SEBASTES MARINUS,* AND ITS RELATIONSHIP TO THE BEHAVIOR OF THE FISH.—A most interesting association of host and parasite is found between the rosefish, *Sebastes marinus* (Linnaeus), and the copepod parasite *Sphyrion lumpi* (Krøyer). The latter, while recorded only rarely on several other species of fishes in Danish, British and American waters, is found abundantly on rosefish inhabiting waters of the Gulf of Maine. Little is known about the life history of *Sphyrion lumpi.* Krøyer (1863, Naturh. Tidsskr. Ser. 3, 2: 399–402) showed drawings of a larval form removed from the egg capsule which Wilson (1919, Proc. U.S. Nat. Mus., 55: 549–604) believed to be a free-swimming copepodid stage. Wilson further reported the male copepod to be 2 mm. long, 1 mm. wide and 5 mm. at its greatest thickness. No males were found by the writer, although parasites on thousands of rosefish were examined.

The form commonly found on the rosefish, and the one to be discussed further here, is the female. In the female *Sphyrion lumpi* the cephalothorax and a part of the neck are firmly embedded in the fish's flesh while the remainder of the neck and trunk are external (Fig. 1). Some idea of the size of the female is indicated by the measurements given by Nigrelli and Firth (1939, Zoologica, 24 (1): 1–10) of the trunks of 20 specimens which ranged from 9 to 12.5 mm. in length, 10 to 15 mm. in width, and 3 to 8 mm. in thickness.

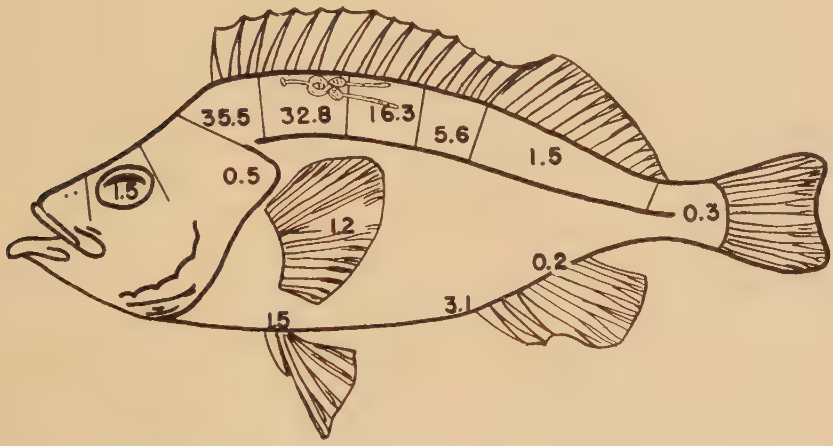

Fig. 1. Outline of the rosefish showing percentage distribution of attachment sites by the copepod parasite *Sphyrion lumpi.*

On the basis of museum material, which showed a concentration of copepods near the dorsal surface of the body of the fish, Wilson concluded that the parasite seeks to reach the dorsal aorta to assure itself of a copious supply of the host's blood as food. Nigrelli and Firth agreed that the blood of the host is the copepod's source of food. However, although they found that the copepod is present mostly in the region between the lateral line and the base of the dorsal fin, the area offering the easiest access to the dorsal aorta, they also report that "the parasite very seldom reaches a large (blood) vessel, and in no cases did they reach as far as the dorsal aorta." Their studies showed that mechanical and chemical stimulation of the host's tissue caused an inflammatory reaction which resulted in marked dilation of the adjacent blood vessels and a pouring out of their contents into the surrounding tissue. The overflowing blood elements are considered the source of nutriment for the parasite.

Nigrelli and Firth's findings would indicate that the concentration of copepods in the region between the lateral line and the base of the dorsal fin is due to something other than ready accessibility to the blood supply of the dorsal aorta. To study the matter further the position of the copepod on the body of the rosefish was recorded, during the period from November, 1942 through October, 1943. A total of 736 copepods were examined. The results are summarized in Figure 1. The heaviest infection was found in the region between the base of the dorsal spines and the lateral line, accounting for 90.2 percent of all the copepods examined. Of the 90.2 percent, 35.5 percent was contained in the area between the nape and the third dorsal spine, 32.8 percent between the fourth and seventh dorsal spines, 16.3 percent between the eighth and eleventh dorsal spines, and 5.6 percent between the twelfth and last dorsal spines. The majority of the parasites in the region were closer to the base of the dorsal spines than to the lateral line. Continuing posteriorly, only 1.5 percent of the copepods examined were found at the base of the dorsal rays, and 0.3 percent on the caudal peduncle. The remaining 8 percent of the copepods were found near the bases of the anal, pelvic and pectoral fins, in the anal opening, on the head, and on the eye.

In the writer's opinion the positional pattern of *Sphyrion lumpi* on the rosefish can be explained by the behavior pattern of fish when attacked by external parasites. Other species of fish infected with external parasites have been observed, both in aquaria and in the field, to dart rapidly toward the bottom or toward a solid object and upon reaching it to roll over and scrape their sides. The roll is not complete and the dorsal margin of the fish, particularly in the humped anterior region, is little affected by the scraping action. Thus parasites attaching themselves at the "hump" are relatively undisturbed compared with those on other regions of the body. The scraping action would also be less effective any place on the body protected by folds of flesh or by protruding fins.

Taking the above data and observations into account, my explanation for the positional pattern of copepod infection of the rosefish is as follows: The free swimming larvae of *Sphyrion lumpi* attack indiscriminately all external parts of the body of the rosefish. The fish, by its rolling movement against the bottom or a solid object scrapes the larvae from most of the body. However, the dorsal hump is comparatively little disturbed by this action and therefore shows a high degree of parasite infection. Other parts of the body which are protected from the cleansing action by folds of skin, such as the eye and anal opening, or by fins, are rather persistent sites of infection.—Alfred Perlmutter, *State of New York Conservation Department, 65 W. Sunrise Highway, Freeport, L. I., N. Y.*

FISHERIES RESEARCH BULLETIN NO. 13

THE NUTRITION OF TROUT
CORTLAND HATCHERY REPORT NO. 18

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The Cortland Experimental Hatchery is operated under a cooperative agreement between the New York State Conservation Department, The Fish and Wildlife Service of the United States Department of the Interior, and Cornell University.

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SUMMARY

Studies upon "blue-slime" disease of brown trout showed a correlation with the biotin storage in the liver of the fish. Diseased fish always contained low levels of the vitamin in their livers. Feeding a biotin source, such as beef liver or dried brewer's yeast, prevented the symptoms of "blue-slime". Both of these products were capable of "curing" the fish after the disease had appeared. Analyses of the livers of "cured" trout showed a normal storage of biotin in the liver. The inclusion of dried egg white in a fortified diet produced the typical symptoms of "blue-slime" disease within eight weeks, indicating that a lack of biotin is the cause of this disease. The typical symptoms of "blue-slime" appeared among brook and rainbow trout after a change in one of the diet ingredients. This condition was corrected with dried brewer's yeast. This suggests that our usual hatchery diets are closer to a biotin deficiency than is commonly thought.

Cod liver oil increased the rate of growth of rainbow trout. Brook trout, because of "blue-slime", failed to reproduce previously reported results with this oil. Biotin fortified diets permitted an excellent response as to growth of brown trout when cod liver oil was added.

Fats of varying melting points were fed to brook trout. It was possible to alter not only the fat content of the body, but the character of the body fat itself. The deposition of fat proved an excellent index to the degree of utilization of these substances. Weight was gained by the deposition of fat at the expense of protein in the body.

The accumulation of ammonia in the water, altered the blood picture of the trout. Carbon dioxide and nitrogen increased in the blood with an increase of water ammonia, but the oxygen of the blood showed a sharp decrease. An increase of metabolic products in the water results in a decrease in the ability of the fish's blood to unite with oxygen. The effect was noticeable even at levels as low as 0.3 p. p. m. ammonia in the water. The accumulation of metabolic products may be prevented by increasing the water flow, decreasing the weight of fish in the pond or by lowering the level of water to increase the number of water changes per hour.

The use of certain commercial liver extracts gave some indications of a cure of the anemia developed when trout are fed a synthetic diet. Of several tested, only two gave such a response.

Several commercial products were tested for fish food. Dried distillers solubles shows promise as a dry concentrate for trout diets. Two canned products were failures when fed alone but gave good results when partially substituted for the meat portion of the diet. A canned trout food prevented anemia, resulted in a low loss of fish, but produced an inferior growth rate.

Preliminary work is reported upon the changes that trout undergo after stocking. The most marked changes occurred in the fat content of the bodies and in the character of the fat.

BIOTIN IN THE DIET OF BROWN TROUT

For the past ten years or so brown trout reared in the New York State Hatcheries and those of the Federal Service of Region 5, have shown a rather peculiar disease that has been called "blue-slime" or "slime-patch" disease. This condition is characterized by the appearance of a bluish slime over the surface of the fish that eventually sloughs away giving the fish a patched appearance. The mortality rate has been severe and all methods of treatment tried have failed to produce beneficial results.

The recognition of this condition roughly corresponds to the time when wide spread use of dry concentrates in the diet of trout became a general practice. At the same time spleens (both beef and pork) were placed in the diet in place of the livers commonly used in the earlier days of fish-culture. This has led to the speculation that dry concentrates were detrimental to brown trout and many believe they should be omitted from the diet.

"Blue-slime" has been called a dietary disease and its appearance about the time of a general change in feeding practices has certainly led support to this belief. However, in the majority of instances it has been noted that the disease appeared about the same time each year, and after a period those trout that survived the outbreak apparently recovered completely, without any change in the diet whatsoever.

Certainly the above description of the disease is conflicting and it has been rather difficult to state whether or not this condition was of a dietary origin or whether it was caused by some micro-organism.

In 1947 Phillips et al reported in their biotin studies, that brown trout required a greater amount of biotin in the diet to cause a maximum storage of this vitamin in their livers than did either brook or rainbow trout. Rodgers (1949) felt that in view of these results the effect of a biotin source upon trout infected with "blue-slime" might prove to be an interesting study. He found that the addition of beef liver to the diet of brown trout showing symptoms of "blue-slime" disease soon erradicated the condition and, as long as beef liver was present in the diet, the fish remained free of trouble. Phillips et al (1949) reported that brown trout fed cod liver oil showed an increased incidence of "blue-slime" and an increased mortality of the fish. Since biotin is a growth factor and since cod liver oil increased the rate of growth of these fish, these authors postulated that perhaps biotin was the preventative agent of "blue-slime" disease.

This past summer a series of experiments were designed to attempt to correlate "blue-slime" disease with a lack of biotin in the diet.

METHOD

Brown trout were fed diets that contained ingredients that furnished a wide range of biotin. This was accomplished by using a base diet of beef melts and the standard No. 6a mixture. This diet was then fortified by the addition of either beef liver or dried brewers yeast. The diets used have been summarized in Table 1.

The fish were handled according to the established procedure of this hatchery(Tunison et al, 1939) and the experiments were run for a period of 20 weeks.

The fish were examined periodically for the appearance of the typical symptoms of "blue-slime" disease.

At intervals differing by about five weeks, trout were killed, their livers removed and analyzed to determine the biotin content. The method used for these analyses has been previously described (Phillips et al, 1947). Three such series of analyses were made during the experimental period. The purpose of this portion of the study was to correlate the level of biotin in the diet, storage of the vitamin in the liver and the size of the fish with the occurrence of "blue-slime" disease.

Since water temperature might have an effect upon the results, some of the diets were run at two water temperatures. One group was held in the upper experimental hatchery in troughs supplied with water at a temperature of 47°F whereas the second group were supplied with water at an average temperature of 52°F.

The data have been summarized in Table 2 and plotted in Chart 1. In Chart 1 the data have been divided into three groups. In the original design of the experiment such a division would not have been necessary but a complete loss of some of the experimental groups forced this division for comparative purpose in order to gain as much information as possible. All differences were tested by analysis of variance.

DISCUSSION

In all experiments it was found that there was a definite correlation between the level of vitamin stored in the liver and the presence or absence of "blue-slime" disease. The severity of the disease as measured by mortality was directly proportional to the presence or absence of biotin sources (beef liver and/ or dried brewer's yeast). As the fish increased in size, the majority of the diets produced a decrease in mortality, an increase in biotin storage in the liver and a disappearance of "blue-slime" disease.

The first three graphs of Chart 1 illustrate a summary of the experiments run in the colder water, for the first two series of analyses. The first graph shows the difference in biotin storage caused by diet. All four diets (1130 through 1133), which contained no liver or yeast, produced trout with extremely low amounts of biotin in their livers. These fish suffered a high mortality and were severely diseased with "blue-slime" at the time of analyses. The second graph illustrates the effect of time upon the liver storage of biotin. This is essentially a function of fish size since the trout were considerably larger at the time of the second series of analysis. Graph 3 brings out the fact that the difference found in series was due to diets Nos. 1134 through 1141, all of which contained biotin fortification. As the fish grew larger they were able to produce a "normal" storage of biotin in their livers without any change in their diets. At the time of the first series of analyses all of these fish showed signs of "blue-slime" disease. These symptoms had disappeared by the time of the second series of analyses.

The second set of three graphs compares the cold water experiments for all three series of analyses. By this time Diets Nos. 1130 and 1131 were complete losses. Essentially the same results may be seen in this set of graphs as were described above. By the time of the third series of analyses the biotin storage of the trout fed the fortified diets had further increased and the losses were normal in all but diets 1132 and 1133 (Table 2). The two groups of trout (Nos. 1132 and 1133) still were severely diseased with "blue-slime", whereas no other group of fish showed such symptoms.

The warm water experiments are graphically described in the third set of graphs of Chart 1. This comparison is for all three series of analyses. It was not possible to include data from the trout which were fed no supplements to the diet since they were a complete loss by the end of the first series of analyses. These experiments again show a difference in biotin storage with time and a difference caused by diet. It is interesting to note that fortification by 10 and 15 percent beef liver (Nos. 1146 and 1147) produced comparatively low storages of biotin in the liver for the first two series of analyses but by the time of the third series, biotin storage was equal to any of the other diets fed. This further strengthens the conclusion that as brown trout grow larger, it takes less biotin in the diet to cause a maximum storage. Both of these diets showed symptoms of "blue-slime" disease through the second series of analyses. No symptoms were apparent by the time of the third series. The mortality of these two diets was again normal by the end of the third series of analyses.

The last set of three graphs in Chart 1, give a comparison of the experiments duplicated at the two water temperatures. This data is for the first series of analysis only because of loss of experimental lots. These graphs show that temperature had little, if any, effect upon the biotin storage and the diets tested for all practical purposes behaved the same under the two conditions.

In general, the appearance of "blue-slime" can be correlated with the storage of biotin in the liver of brown trout. As the fish increased in size, it required less biotin in the diet to produce a "normal" storage of the vitamin in the fish's liver. Temperature was not a factor in these experiments. It now becomes apparent why, in many cases in the past, brown trout "cured" themselves of "blue-slime" without any change in the diet. Those fish that managed to survive the disease merely outgrew the condition as they approached the size that allowed

TABLE 1. Diet composition in percent

Diet number	Beef spleen	Dry[1] mix # 6a	Crisco	Cotton-seed oil	Beef tallow	Beef liver	Cod liver oil	Yeast
1125	50	50						
1126	50	45	5					
1127	50	45		5				
1128	50	45			5			
1130	47	50					3	
1131	47	50					3	
1132	50	50						
1133	50	50						
1134	27	50				20	3	
1135	27	50				20	3	
1136	45	50						5
1137	45	50						5
1138	30	50				20		
1139	30	50				20		
1140	42	50					3	5
1141	42	50					3	5
1142	47	50					3	
1143	47	50					3	
1144	50	50						
1145	50	50						
1146	40	50				10		
1147	35	50				15		
1148	30	50				20		
1149	30	50				20		
1150	42	50					3	5
1151	45	50						5
1152	27	50				20	3	
1153	27	50				20	3	
1154	50					50		
1155	50	50						
1156	50	50						
1157	47	50					3	
1158	47	50					3	
1159	50	50						
1160	50	50						
1161	47	50					3	
1162	47	50					3	
1163	50	50						
1164	50	50						
1165	47	50					3	
1166	47	50					3	
1167	50	50						
1168	50	50						
1169	47	50					3	
1170	47	50					3	

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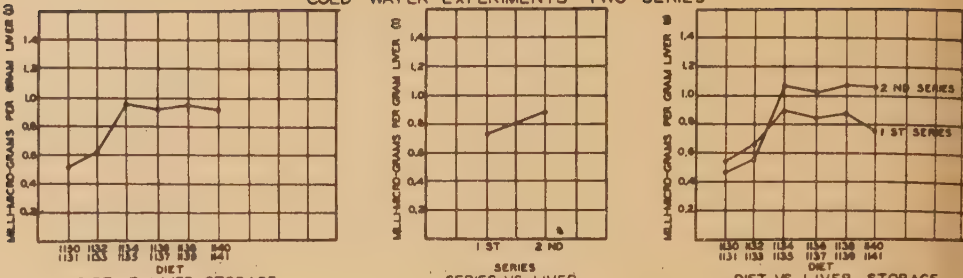
[1] Composed of 24 parts each of wheat middlings and cottonseed meal, 48 parts of fish mea

	First series				Second series				Third series			
Diet number	Average weight of fish grams	Milli-1/ micro-grams biotin per gram of fish liver	Percent loss	"blue-slime"	Average weight of fish grams	Milli-1/ micro-grams biotin per gram of fish liver	Percent loss	"blue-slime"	Average weight of fish grams	Milli-1/ micro-grams biotin per gram of fish liver	Percent loss	"blue-slime"
					Water temperature 47°F							
1130	1.66	0.502	13.9	yes	0.93	0.411	31.4	yes	2/--	------	------	----
1131	1.74	0.609	3.5	yes	1.64	0.543	27.0	yes	2/--	------	------	-----
1132	1.56	0.568	12.0	yes	0.96	0.543	23.6	yes	0.63	0.331	26.0	yes
1133	1.83	0.674	15.2	yes	1.72	0.600	29.1	yes	2.75	0.436	86.0	yes
1134	2.06	0.936	2.1	yes	3.78	1.058	4.1	no	7.05	1.192	1.2	no
1135	2.12	0.849	3.4	yes	3.72	1.066	2.1	no	7.03	1.083	0.9	no
1136	1.88	0.833	3.3	yes	3.30	0.993	2.7	no	6.05	1.136	1.2	no
1137	1.88	0.827	1.3	yes	3.44	1.034	1.2	no	6.04	1.097	1.0	no
1138	1.81	0.882	3.3	yes	3.08	1.026	6.4	no	6.00	1.203	1.8	no
1139	1.83	0.846	3.3	yes	3.10	1.103	6.5	no	5.89	1.323	1.5	no
1140	1.98	0.823	2.9	yes	3.60	1.035	1.6	no	6.90	1.102	0.9	no
1141	1.90	0.752	2.4	yes	2.37	1.058	1.9	no	6.50	1.199	0.9	no
					Water temperature 52°F							
1142	1.57	0.506	17.7	yes	2/--	------	------	----	------	------	------	-----
1143	1.42	0.531	15.2	yes	2/--	------	------	-----	------	------	------	------
1144	1.53	0.670	15.0	yes	2/--	------	------	-----	------	------	------	------
1145	1.44	0.632	16.6	yes	2/--	------	------	-----	------	------	------	------
1146	2.01	0.721	10.5	yes	4.79	0.759	11.4	yes	12.1	1.270	1.7	no
1147	1.86	0.795	5.8	yes	3.90	0.979	9.4	yes	9.9	1.190	0.5	no
1148	1.84	0.939	5.0	yes	4.30	1.069	8.0	no	12.1	1.080	1.3	no
1149	2.02	0.887	6.0	yes	3.96	1.028	8.5	no	10.4	1.059	0.6	no
1150	2.18	0.926	4.8	yes	3.50	1.031	4.8	no	14.1	1.130	0.7	no
1151	2.02	0.889	2.4	yes	4.74	1.016	7.8	no	12.0	1.249	0.0	no
1152	2.09	0.868	2.9	yes	4.51	1.096	5.5	no	12.3	1.296	0.8	no
1153	2.15	0.877	3.1	yes	4.64	1.202	5.0	no	12.8	1.232	0.3	no
1154	1.71	0.929	0.4	no	2.14	1.153	0.2	no	5.7	1.032	0.4	no

1/ Expressed in thousands.

2/ Experiment discontinued at this time because of complete mortality.

COLD WATER EXPERIMENTS TWO SERIES

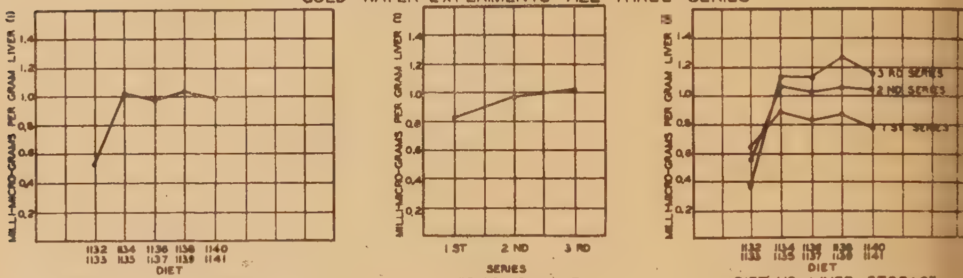


DIET VS. LIVER STORAGE

SERIES VS. LIVER STORAGE

DIET VS. LIVER STORAGE TWO SERIES COMPARED

COLD WATER EXPERIMENTS ALL THREE SERIES

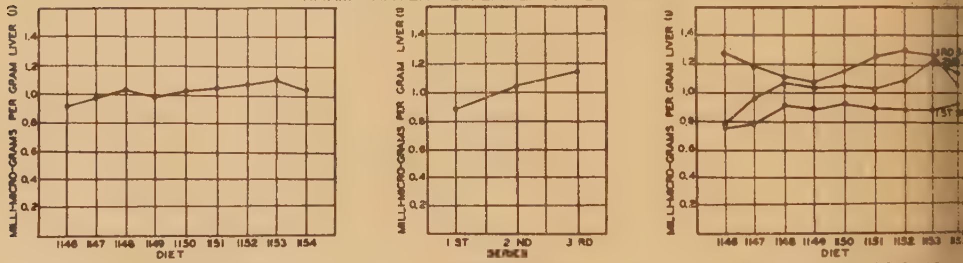


DIET VS. LIVER STORAGE

SERIES VS. LIVER STORAGE

DIET VS. LIVER STORAGE THREE SERIES COMPARED

WARM WATER EXPERIMENTS ALL THREE SERIES

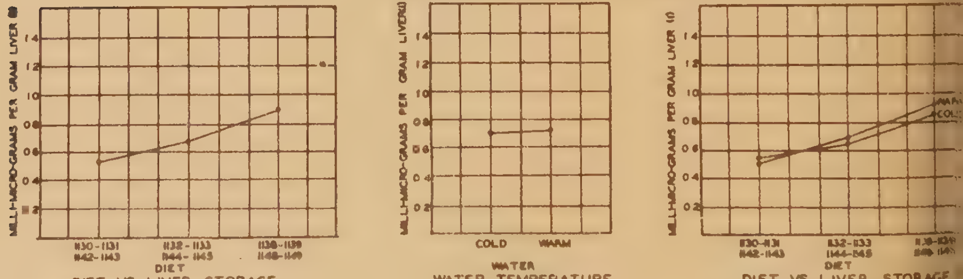


DIET VS. LIVER STORAGE

SERIES VS. LIVER STORAGE

DIET VS. LIVER STORAGE THREE SERIES COMPARED

COLD AND WARM WATER EXPERIMENTS FIRST SERIES



DIET VS. LIVER STORAGE

WATER TEMPERATURE VS. LIVER STORAGE

DIET VS. LIVER STORAGE TWO WATER TEMPERATURES C

(1) EXPRESSED IN THOUSANDS

Chart 1. Graphic Description of the Biotin Experiments.

"normal" storage of biotin from the vitamin content of the diet.

One experiment, No. 1154, received 50 percent of its diet as liver, the remaining portion being beef spleen. These fish showed good storage of biotin throughout the experimental period and at no time were there indications of "blue-slime" disease. Since the next highest level of fortification was either 20 percent beef liver or 5 percent yeast, and since these levels did not prevent the appearance of "blue-slime", it is obvious that for trout under 2 inches in length, the fortification must be increased. From available information it now appears that either 33 1/3 percent beef liver or 8 percent dried brewers yeast would be advisable. For larger fish these levels may be substantially reduced.

It is interesting to note the low rate of gain of the fish fed the all meat diet (No. 1154) as compared to those receiving a dry food supplement. This certainly shows the value of dry concentrates in the diet of brown trout.

Since these experiments merely correlated the level of biotin in the liver of the trout with the appearance of "blue-slime" among the fish, two experiments were designed to try and definitely connect biotin itself with the condition.

Dried egg white in the diet of higher animals is capable of causing a biotin deficiency. It was thought, therefore, that if egg white were added to the diet of brown trout, the appearance of the typical characteristics of "blue-slime" would show a definite relationship between biotin and "blue-slime" disease. Accordingly experiments were set up in which one group of brown trout received a diet fortified with yeast and a second a similar diet with the addition of dried egg white. 1/ Unfortunately these experiments were not undertaken until the fish averaged about 14 grams in weight and the factor of fish size was a controlling factor of the results.

After a period of about 8 weeks "blue-slime" disease made its appearance among the fish fed the egg white whereas it was absent from the control group. Analyses of the livers of these fish showed a storage of 534 milli-micro-grams per gram of liver among the fish fed the egg white and a storage of 1,217 milli-micro-grams among the control fish. No excessive losses were recorded in either group. The lack of mortality can probably be explained by the large size of trout used in these experiments.

For the first time this year "blue-slime" was noted among rainbow trout and to a greater degree it was found in our brook trout. In fact it was so severe in the brook trout, a considerable loss resulted and the rate of growth was greatly reduced. No excessive losses resulted among the groups of rainbow trout.

An analysis of the liver of these fish showed that the storage of biotin in their livers was extremely low. The symptoms of "blue-slime" appeared shortly after the first of July with no apparent reason. However, it was known that one diet change did occur that might account

1/ Kindly supplied by Armour and Company.

for the sudden appearance of "blue-slime" disease. About the first of July a new supply of fish meal was added to the dry food of the diet, a meal that was obviously of poor quality. Since this was the only diet change known, a sample of the meal was analyzed for its biotin content. It contained less than half of the amount of biotin found in the fish meal previously used and since fish meal forms 24 percent of the total diet, this resulted in a considerable reduction in the biotin intake of these fish. The diet was then supplemented with 5 percent of dried brewer's yeast, the "blue-slime" characteristics disappeared and analyses of the trout's liver showed a normal storage of the vitamin.

It is now more clearly understood why "blue-slime" disease appeared about the time of widespread use of dry foods and the accompanying substitution of spleens for livers. Neither the spleens nor the dry foods are good sources of biotin and their use left the path open for a biotin deficiency.

In view of these results it would seen advisable to add to the dry food portion of the diet, sufficient dried brewer's yeast so that when the diet is mixed with the meats there will be an equivalent of 5 percent brewer's yeast in the diet of all hatchery reared trout (brooks, browns and rainbows). Beef liver may be used in place of the yeast but the cost and availability of yeast show it to be a valuable supplement for trout diets.

URTHER STUDIES ON THE USE OF COD LIVER OIL IN THE DIET OF TROUT

Phillips et al (1948) reported that cod liver oil added to the diet of trout resulted in an increased rate of growth of these fish. These experiments were conducted at a water temperature of 47°F and therefore did not necessarily show the effect of the oil at the usual hatchery water temperatures. This past summer another set of experiments were made in which the effect of cod liver oil on the growth rate was measured at two water temperatures (47°F and 52°F) upon three species of trout (brook, brown and rainbow). In addition other experiments were designed to determine what effect the oil would have upon the growth of brown trout whose diet was supplemented with a source of biotin to control the effect of "blue-slime" disease upon the growth pattern. The experiments were run for a period of 20 weeks.

The diets used are listed in Table 1 and the results summarized in Table 3.

Due to the severity of "blue-slime" disease all brown trout experiments whose fish were fed unfortified diets had to be discontinued because of a complete loss of fish.

In those experiments in which a fortified diet was employed, the addition of cod liver oil to the diet of brown trout resulted in an increased rate of growth (Nos. 1134 and 1135 compared to 1138 and 1139) (1140 and 1141 compared to 1136 and 1137). It would therefore appear that, at least in cold water, the addition of biotin supplements resulted in a maximum benefit from the addition of cod liver oil. These fish did show some incidence of "blue-slime" during the early part of the experiment, but this disappeared as the fish became larger (see section on biotin).

Rainbow trout responded well to the addition of cod liver oil to the diet at both of the temperatures tested. There was an increased rate of growth with the addition of the oil and the degree of increase was about the same at the two water temperatures. The effect of the oil on the rate of growth is in agreement with previously reported experiments.

In the cold water experiments the rate of growth of brook trout was not changed by the addition of cod liver oil and in the warm water groups the addition of oil actually decreased the rate of growth. These results are not in agreement with our previously reported experiments (Phillips et al, 1948). However this year, as explained in an earlier section, "blue-slime" was noted among these trout which adversely affected the growth rate. The addition of yeast to the diet corrected this condition and the rate of growth became more nearly that expected for fish of this size but so much damage had been done that the fish never fully made up for their lack of growth during the disease period. These experiments certainly emphasize the importance of the use of supplements in the diet of these fish where products used may vary sufficiently to cause the development of a serious condition. It also points out that, at least in the case of brook trout, the normally used diet of this area is closer to a deficiency condition than was perhaps previously thought.

Cod liver oil can be of benefit in causing an increased rate of growth but precautions must be taken to prevent the magnification of a biotin deficiency.

TABLE 3. Summary of cod liver oil experiments

Diet number	Species of trout	Average weight fish at start grams	Average weight fish at end grams	Gain weight fish grams	Total percent gain	Average monthly percent mortality	Total conversion
Water temperature 47°F							
1155	Rainbow	1.63	9.27	7.54	462.0	4.3	5.0
1156	Rainbow	1.63	10.96	9.33	572.0	2.7	5.0
1157	Rainbow	1.63	11.41	9.78	600.0	3.5	4.5
1158	Rainbow	1.63	12.40	10.77	661.0	3.8	4.4
1130*	Brown	1.03	1.31	0.28	27.0	19.6	20.2
1131*	Brown	1.03	1.50	0.47	46.0	20.7	8.9
1132*	Brown	1.03	1.31	0.28	27.0	20.9	8.8
1133*	Brown	1.03	1.64	0.61	59.0	12.9	7.5
1159	Brook	0.93	7.20	6.27	674.0	2.3	4.2
1160	Brook	0.93	4.67	3.74	402.0	1.6	5.1
1161	Brook	0.93	6.10	5.17	556.0	5.6	4.4
1162	Brook	0.93	6.06	5.13	552.0	6.0	4.4
1134	Brown	1.03	7.05	6.02	584.0	2.3	4.5
1135	Brown	1.03	7.03	6.00	583.0	1.8	4.5
1138	Brown	1.03	6.00	4.97	483.0	3.7	5.0
1139	Brown	1.03	5.90	4.87	473.0	3.5	4.9
1140	Brown	1.03	6.90	5.87	570.0	1.7	4.1
1141	Brown	1.03	6.50	5.47	531.0	1.6	4.7
1136	Brown	1.03	6.05	5.03	488.0	1.6	5.0
1137	Brown	1.03	6.04	5.01	486.0	1.2	4.9
Water temperature 52°F							
1163	Rainbow	1.63	18.05	16.42	1007.0	2.1	3.5
1164	Rainbow	1.63	15.30	13.67	839.0	10.9	3.8
1165	Rainbow	1.63	22.40	20.77	1274.0	1.9	3.0
1166	Rainbow	1.63	19.90	18.27	1121.0	1.7	3.1
1142**	Brown	1.03	1.48	0.45	43.0	22.2	4.8
1143**	Brown	1.03	2.00	0.97	94.0	22.1	29.6
1144**	Brown	1.03	2.02	1.89	183.0	24.2	6.6
1145**	Brown	1.03	2.92	1.89	183.0	22.1	6.3
1167	Brook	0.93	9.62	8.69	934.0	1.9	3.9
1168	Brook	0.93	11.26	10.33	1111.0	0.8	3.3
1169	Brook	0.93	4.85	3.92	421.0	4.5	4.9
1170	Brook	0.93	6.79	5.88	630.0	2.3	4.4

* These experiments concluded after 8 weeks because of excessive losses.

** These experiments concluded after 4 weeks because of excessive losses.

THE EFFECT OF DIETARY FAT UPON THE CHEMICAL COMPOSITION OF THE BODY OF TROUT

Previous experiments have shown that it is possible to cause a variance in the chemical composition of the trout's body by altering the composition of the diet fed the fish (Phillips et al, 1948). This past summer these studies were continued in which fats of different melting points were added to a base diet fed to brook trout.

Three fats were selected: an oil (cottonseed oil), a relatively soft fat (crisco) and a relatively hard fat (beef tallow). These were added at a level of five percent to a base diet composed of 50 percent beef spleen and 45 percent of dry feed mixture No. 6a. The experiments were run for a period of 20 weeks according to the established procedure of this hatchery (Tunison et al, 1939). At two intervals, differing by about two months, samples of the fish were taken and their bodies analyzed as described previously (Phillips et al, 1948).

All results were tested by means of analysis of variance.

The composition of the diets employed is listed in Table 1 and the results summarized in Tables 4 and 5. Table 4 gives the results based upon the residue remaining after dehydration of the fish's body. These results have been converted to a "wet" basis in Table 5. The results have been summarized graphically in Chart 2.

The percent water of the fish's body was essentially the same for all diets fed. The addition of the various fats, therefore, did not cause any differences in the water content of the trout's body.

The addition of the fat itself to the diet, did not cause any significant ash deposition in the trout's body but there was a significantly greater amount of ash at the time of the second series of analyses. This is a function of fish size and/or age rather than of diet.

The protein content of the body was altered by the diet change. This alteration was slight but significant. The time of analyses, a function of fish size and/or age, had no effect on the protein deposition in two of the diets but did change in the bodies of the control fish and those fed the beef tallow. It is interesting to note that it is these two lots of fish that produced the least amount of fat in their bodies.

The greatest difference was noted in the differences of fat deposition caused by the diets fed. Both the crisco and cottonseed oil diets caused a highly significant increase in the fat content of the trout's body. The addition of beef tallow had no such effect. This in itself is a measure of the utilization of the various fats used in these diets. The indications are that crisco and cottonseed oil were utilized by the fish whereas beef tallow added little if any to the diet. There was an increase in deposition of fat as the fish became larger and older in all cases but that of the cottonseed oil. The latter diet caused no increase at the time of the second analyses but a glance at Table 4 will show these fish gained at a much slower rate than did any of the other experimental lots (note column average weight of fish). At the conclusion of these experiments there were no indications of an edema from these soft fats which might have accounted for the low rate of growth (Phillips et al, 1940). However it is possible that such a condition was developing.

TABLE 4. The effect of dietary fat upon the chemical composition of the body of trout 1/

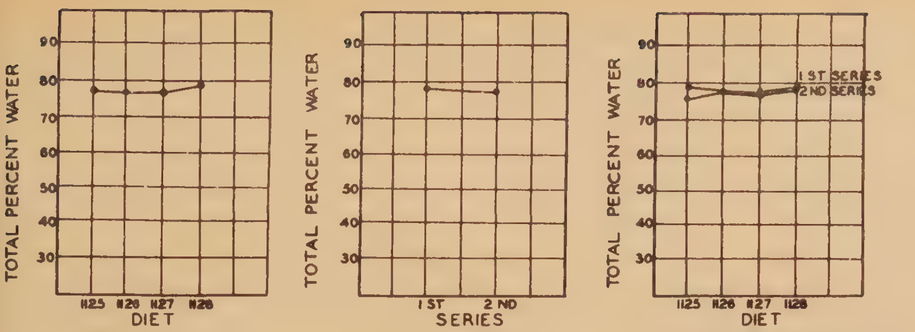
Diet number	Percent fat	Iodine number	Percent protein	Percent ash	Percent water	Average weight of fish, grams
First Series						
1125	20.5	90.9	60.4	9.8	79.3	4.72
1126	24.7	96.9	55.8	9.1	77.6	4.39
1127	28.6	107.5	52.7	9.2	77.2	3.61
1128	20.5	92.3	62.3	9.7	79.5	4.95
Second Series						
1125	23.2	95.4	57.0	10.1	76.1	8.10
1126	25.7	98.3	54.8	9.8	77.7	8.28
1127	28.2	110.0	52.1	9.7	77.0	5.69
1128	24.5	92.3	56.6	10.0	78.6	8.50

1/ Analyses expressed in relation to the dry weight of the trout.

TABLE 5. The effect of dietary fat upon the chemical composition of the body of trout 1/

Diet number	Percent fat	Iodine number	Percent protein	Percent ash	Percent water
First Series					
1125	4.2	90.9	12.5	2.0	79.3
1126	5.6	96.9	12.5	2.0	77.6
1127	6.5	107.5	12.0	2.1	77.2
1128	4.2	92.3	12.8	1.9	79.5
Second Series					
1125	5.6	95.4	13.6	2.4	76.1
1126	5.8	98.3	12.2	2.2	77.7
1127	6.5	111.0	11.9	2.3	77.0
1128	5.3	92.3	12.1	2.1	78.6

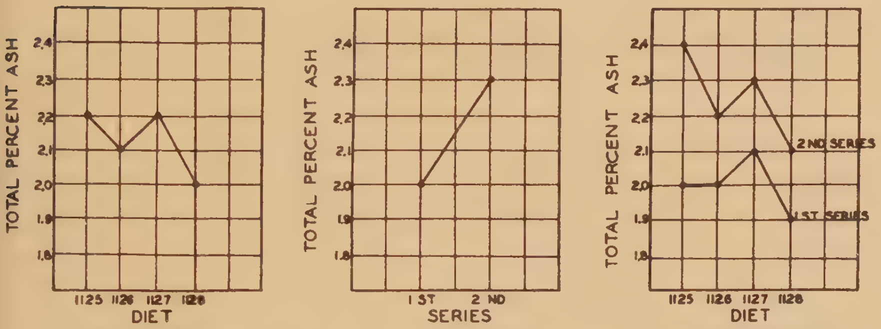
1/ Analyses expressed in relation to the original wet weight of the trout.



DIET VS. PERCENT WATER

TIME VS. PERCENT WATER

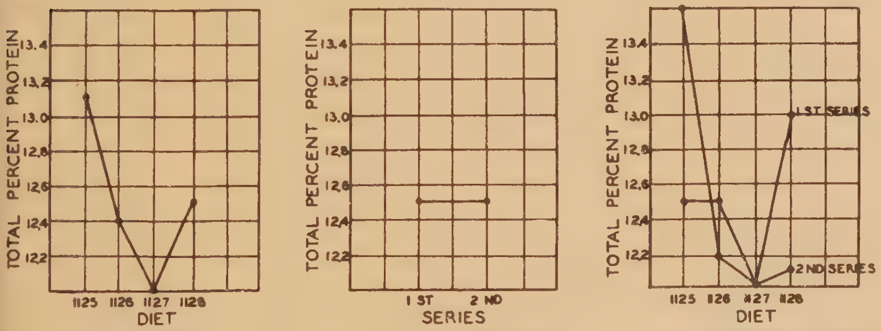
DIET VS. PERCENT WATER TWO SERIES COMPARED



DIET VS. PERCENT ASH

TIME VS. PERCENT ASH

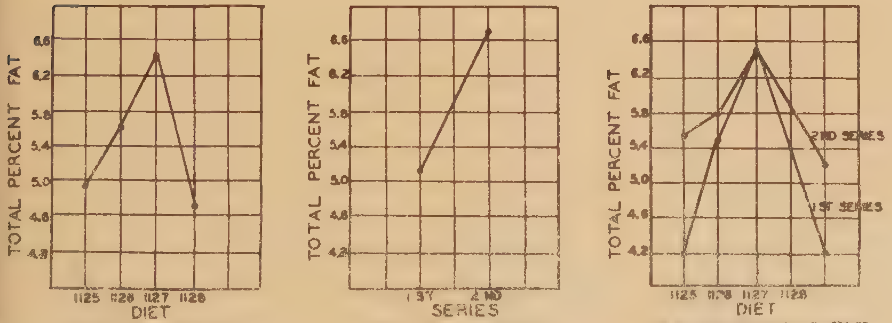
DIET VS. PERCENT ASH TWO SERIES COMPARED



DIET VS. PERCENT PROTEIN

TIME VS. PERCENT PROTEIN

DIET VS. PERCENT PROTEIN TWO SERIES COMPARED



DIET VS. PERCENT FAT

TIME VS. PERCENT FAT

DIET VS. PERCENT FAT TWO SERIES COMPARED

Chart 2. Graphic description of the body composition experiments.

Again referring to Table 4, a rather interesting comparison can be noted. The average weight of the fish fed the crisco diet was about equal to the weights of the fish fed both the control diet and the food containing the beef tallow. Since the fat content of the crisco fed fish was much higher than either of these two other lots of fish, the gain in weight was due to fat deposition rather than an actual growth of body tissues. This certainly raises a point in the evaluation of gains of fish From the economy point of view, the crisco fed fish did not produce as much fish flesh as did the other two diets and although the rate of growth was the same, the actual fish production was different. The use of any of these three fats failed to cause any beneficial effects as measured by growth rate and in the case of cottonseed oil, detrimental effects were noted.

The iodine number of the fat of the trout's body showed a direct relationship with the fat fed. There was no difference between the iodine number of the fat and the control fish and that of the trout fed beef tallow. This is further proof of the poor absorption and utilization of the hard fat. Crisco in the diet resulted in a slight increase in the iodine number whereas cottonseed oil produced a much greater value. This is to be expected since the animal does tend to reflect the characteristics of the food fat in its own body.

It would appear from these results that the actual chemical composition of the trout's body would be an additional aid in judging the growth of trout from the point of view of flesh production.

In general, where comparison is possible, the results obtained this year agree reasonably well with those found previously (Phillips et al, 1948).

METABOLIC PRODUCT ACCUMULATION AND ITS EFFECT

As previously reported (Phillips et al, 1948) the accumulation of metabolic products in ponds is related to the number of fish, water temperature, and the rate of water change per hour. Little is known about the metabolism of trout. However, evidence indicates that at any one temperature, trout, while in a resting state, have a fairly constant rate of excretion of ammonia. This rate increases with the activity of the fish and with a rise in water temperature. With a 13 degree rise in temperature (47-60°F) this excretory rate may increase ten-fold. Excreted through the gills, along with the ammonia, are the other readily diffusible metabolic products (urea, and amine and amine oxide derivatives). If these products are allowed to accumulate, even though the tolerance limit may not be reached, the environmental change may adversely affect the fish. As the concentration rises the fish fail to maintain the normal blood level of oxygen and lose the ability to utilize the oxygen that may be available.

The excretory product of respiration is carbon dioxide. It has been reported (Irving et al, 1941) that as the carbon dioxide tension in the blood increases there is a decrease in the affinity of the hemoglobin for oxygen. Increases in temperature further decrease the degree of oxygen saturation of the blood in the presence of carbon dioxide.

Ammonia has been used as the index of metabolic product accumulation. This product was selected because a direct method of analysis was applicable. A 10 ml. water sample was nesselerized with 1 ml. standard Nesseler's solution, allowed to stand for five minutes and the color developed was read directly in a Lumetron photo-electric colorimeter and interpreted from a standard curve.

This year preliminary work was begun on blood gas analyses. The improved Van Slyke Blood Gas Apparatus was used for this work. However, because of unforseen events, the analyses were not started until late in the summer which necessitated the use of larger (5-6 inch) trout. It is planned to repeat the work this year using smaller fish. It is believed that the adverse effects of metabolic product accumulation will be more pronounced on smaller fish during the period of more rapid growth and higher metabolic rate.

The blood samples were drawn directly from the heart in a Luer syringe containing 0.05 ml. of de-aerated 30% potassium oxalate. The samples were kept under oil until they were placed in the extraction chamber of the apparatus. The only variation from the customary Peters-Van Slyke procedure was an extended extraction period of from three to eight minutes.

The fish previous to analyses were held in aquaria in which the water was recirculated. The recirculation maintained a satisfactory oxygen level while at the same time the metabolic products were increasing in concentration. At intervals, as the ammonia increased, fish were removed and placed in an electrical shocking trough where they were temporarily paralyzed to facilitate removal of the blood sample.

The fish were then returned to a regular hatchery trough where they soon recovered. In some cases, fish so treated were used again after a 48 hour recuperative period.

Preliminary data show that as the ammonia concentration in the water increases to approximately 1.0 p.p.m. the blood picture is drastically altered. The carbon dioxide content of the blood increases 0.3 volume percent; the nitrogen content increases 0.15 volume percent; and the oxygen content decreases 0.7 volume percent. This indicates that as the metabolic products are allowed to accumulate the blood of the fish rapidly loses its ability to unite with oxygen. Even with small degrees of increased concentration the fish may suffer partial suffocation. This may explain why, even with sufficient available oxygen, there may be an increased mortality rate in the last member of a series of ponds. This effect is definitely noticed as soon as the ammonia concentration reaches 0.3 p.p.m.. Therefore, it behooves fish culturists to keep the ammonia content of their pond waters as low as possible.

The rate of ammonia accumulation is directly proportional to the weight of fish per cubic foot of water, and to the rate of change per hour of the water in which the fish are being held.

Until we can ascertain the direct physiological effect of this lowering of blood oxygen on the well-being of the fish, and the level at which this depletion becomes serious, no positive recommendations may be made. Literature values place a maximum of 0.1 p.p.m. of ammonia that should be tolerated in waters used for fish culture. With this low ammonia value in usable water, and 1.0 p.p.m. taken as indication of actual pollution, the danger point must lie within this range. Although using increased mortality as the criterion of the critical limit it may well be that concentrations below this (even as low as 0.1 p.p.m.) adversely affect the normal metabolism and hence the growth rate and other normal physiological functions. For this reason it is suggested that wherever possible the ammonia content should be kept below 0.2 p.p.m..

At present the control of this ammonia and the other metabolic products involves either the reduction of fish weight per cubic foot of water, or an increase in the volume of water passing through the pond (i. e. the rate of water changes per hour must be increased). To cut the fish weight necessitates more ponds into which the fish may be placed, and usually further space is not available. The other alternative is to increase the flow of water. Unfortunately trouble from these metabolic products often arises during the period of the year when the water temperatures are the highest, and the water flow the lowest, with all available water being utilized. However, conditions may be bettered considerably by lowering the water levels in the ponds and thereby, because of lowered volume increasing the rate of water change. Accumulated data indicates that, in spite of the fact that the fish weight per cubic foot is increased, the increased dilution resulting from the increased rate of water change is sufficient to overcome the effects of the weight increase resulting from lowered volume.

ANEMIA IN BROOK TROUT

Anemia experiments were continued this year. Liver fractions 1/ and vitamin supplements were either fed or injected into anemic brook trout in an effort to restore a normal blood count or at least get a definite response.

Following the usual procedure of this laboratory the anemia was caused by feeding a synthetic diet 2/. When the blood count, which normally runs between 1,000,000 and 1,500,000 red corpuscles per cubic millimeter had dropped to below 800,000 the administration of supplements was started.

The fish were separated, for treatment, into lots of 25 fish each. Each lot was treated with one of the various supplements for a period of seven days. Blood counts were made at the end of each period. In the case of the negative control (those receiving the synthetic diet) the number of fish in the lot was greater and fish were removed from this lot for experiment at seven day intervals. This means that the blood count of these fish at the end of any period became the starting count of these experimental lots for the following period. Short trial periods were employed because we were primarily interested in trends caused by the various fractions rather than the restoration of a normal count. It was felt that indications of results obtained would be of future benefit in further fractionation of those fractions eliciting a hemopoietic response. The results of these tests are given in Table 6.

Both Biopar A, the whole aqueous liver extract, and Biopar C, the 70% alcohol insoluble portion of the aqueous extract, gave positive responses. These were administered in #5 gelatin capsules containing approximately 0.09 gms. of the extract being tested. The bulk of the extract, the size of the fish, and the slow passage of the capsule through the intestinal tract limited the dosage of these fractions. Under these limiting conditions each fish received one capsule every other day.

Biopar F, the liquid fraction, was injected at the rate of 0.1 ml. every other day. This fraction caused excessive mortality of the fish and wiped out the entire lot during the second trial period. This particular preparation contained 0.5% phenol added as a preservative. Either this or the injection method of administration of this particular product may account for this mortality.

1/ The non-heat coagulable liver fractions supplied by Armour and Company of Chicago, Ill. are as follows:

Biopar A — Whole aqueous extract of liver.
Biopar C — 70% alcohol insoluble portion of the aqueous extract.
Biopar F — A fraction rich in anti-pernicious anemic principles, liver growth factors, and other constituents.

2/ The synthetic diet was composed of: 20 parts casein; 4 parts Osborne — Mendel salt mixture; 5 parts yeast; 3 parts cod liver oil; and 34 parts each of raw corn starch and dextrin.

TABLE 6. Effects of various supplements upon the blood count of anemic brook trout

Supplement	Mode of administration	Blood count 1/		
		1st 7 day period	2nd 7 day period	3rd. 7 day period
Liver 2/	fed	820	1160	1130
Synthetic 2/	fed	498	480	500
Biopar A	capsule	720	750	720
Biopar C	capsule	770	660	690
Biopar F	injection	400	——	310
Vitamin B 12	injection	660	650	460
Vitamin Mixture 3/	injection	490	640	600

1/ Expressed in thousands.

2/ Diets carried throughout the experimental period.
Fish used in other tests were taken for each period from the lot fed the synthetic diet.

3/ Vitamin mixture contained vitamin B 12, folic acid, and biotin.

The responses obtained from the use of both vitamin B 12 and the vitamin mixture containing vitamin B 12, folic acid, and biotin were erratic. However, the limited positive indications will warrant further experimentation with these substances.

PRACTICAL DIETS FOR TROUT HATCHERIES

The practical diets tested this past summer consisted of several commercially available products that have been suggested as trout food. Many of these products, although perhaps not suited for long periods of feeding, might be desirable during times that the usual hatchery foods are difficult to obtain.

All experiments were made with brook trout for a 20 week period except in those cases where excessive losses automatically concluded the experiment. The trout were handled according to the standard procedure of this hatchery (Tunison et al, 1939).

It was not possible to conduct all experiments in the same water supply, therefore one group was held in the experimental hatchery in water at a temperature of 47°F whereas a second group was held in troughs supplied with water at an average temperature of 52°F.

The diet composition is listed in Table 7 and the results are summarized in Tables 8 (47°F water) and 9 (52°F water).

The use of mixture No. 49 (Diets 1171 and 1172) resulted in excellent growth and conversion and a low mortality. These results were superior to those of the control diets (Nos. 1159 and 1160). It is also interesting to note that no evidence of "blue-slime" appeared among these fish whereas the control fish did show such symptoms. It appears that dried distillers solubles contain sufficient biotin to prevent this disease. This product would be a good substitute for either a portion of the fish meal or for dried skim milk. Certainly the 4.5 cents per pound is cheaper than either fish meal or dried milk.

The use of a commercial cat and dog food (No. 1173) as a replacement for one half of the usual level of beef spleen in the diet, did produce growth equal to the control experiments (1159 and 1160). The conversion factor was about equal to the control but the loss was somewhat higher. This product might be suitable as a partial replacement for the spleen of the diet during periods of meat shortages. However, the use of this product as the sole source of food for trout (Diet 1179) would not be recommended. The mortality rate was excessively high, the conversion out of reason, and the rate of growth very low. There was some evidence of a thiamin deficiency entering the picture and this probably accounts for the low rate of growth. Toward the end of the experimental period, the losses were increasing at an alarming rate.

The use of canned carp in the diet as a partial replacement for the usual meat portion of the diet (No. 1174) did produce average results for the first eight weeks of the experiment. Because of a lack of material, this experiment was concluded at this time. This same product as a total food for the trout, was entirely unsatisfactory in that the fish became severely anemic after a period of six weeks (diet No. 1180) and the experiment was concluded.

TABLE 7. Diet composition in percent of feeding experiments

Diet number	Beef spleen	Dry 1/ mix #6a	Dry 2/ mix #49	Canned 3/ cat food	Canned 4/ carp	Commercial 5/ fish food
1159	50	50				
1160	50	50				
1167	50	50				
1168	50	50				
1171	50		50			
1172	50		50			
1173	25	50		25		
1174	25	50			25	
1175		50				50
1176		50				50
1177						100
1178						100
1179				100		
1180					100	

1/ Composed of 24 each of wheat middlings and cottonseed meal, 48 parts fish meal and 4 parts salt.

2/ Composed of 24 parts each of wheat middlings, cottonseed meal, fish meal, dried distillers solubles and 4 parts of salt. Dried distillers solubles kinly furnished by Distillers Feed Research Council.

3/ Kindly furnished by T. C. Slaughter Company, Reedville, Virginia.

4/ Kindly furnished by Lakefish Canning Company, Mankato, Minn.

5/ Kindly furnished by the Perk Foods Company, Chicago, Ill.

TABLE 8. Summary of feeding experiments

Diet number	Average weight start grams	Average weight end grams	Gain in grams	Total percent gain	Monthly average percent loss	Total conversion
1159	0.93	7.20	6.27	674.0	2.3	4.2
1160	0.93	4.67	3.74	402.0	1.6	5.1
1171	0.93	10.01	9.08	976.0	1.7	3.6
1172	0.93	8.35	7.42	798.0	0.8	3.7
1173	0.93	7.41	6.48	697.0	3.8	4.5
1174*	0.93	3.09	2.16	232.0	0.6	4.3
1179	0.93	3.27	2.34	252.0	6.9	7.4
1180**	0.93	2.66	1.73	186.0	7.5	4.4

* Discontinued after 8 weeks because of lack of material.

** Discontinued after 6 weeks because of excessive losses because of a severe anemia.

TABLE 9. Summary of feeding experiments with a commercial fish food

Diet number	Average weight fish at start grams	Average weight fish at end grams	Gain in weight grams	Total percent gain weight	Average monthly percent mortality	Total conversion
1167	0.93	9.62	8.69	834.0	1.9	3.9
1168	0.93	11.26	10.33	1111.0	0.8	3.3
1175	0.93	1.30	0.37	40.0	6.1	20.0
1176	0.93	1.17	0.24	26.0	5.1	29.8
1177	0.93	6.46	5.53	595.0	0.8	4.5
1178	0.93	6.84	5.71	614.0	0.9	4.5

The use of a commercially canned trout food (Table 9, diets 1177 and 1178) gave fair results. The growth rate was inferior to the control diets (Nos. 1167 and 1168) but the fish were in good condition. No anemia developed throughout the period and the losses were low. It was also interesting to note that no sign of "blue-slime" was seen among these fish at any time whereas the control fish did exhibit such a condition as described in an earlier section.

The use of this same product as a replacement for the meat portion of our standard hatchery diet (diets Nos. 1175 and 1176) was a complete failure in that the fish failed to show any significant gains and the mortality rate was excessively high. The best explanation for these results is the mixture could not be "bound" or held together and most of the food became unavailable to the fish.

These experiments indicate that this particular food is capable of rearing trout although the rate of growth was definitely inferior to our standard diets. It certainly could be used as a substitute food during periods of meat shortages and in hatcheries where rapid gains may not be an important factor.

CHEMICAL COMPOSITION OF BROWN TROUT BEFORE AND AFTER STREAM STOCKING

The past year marked the beginning of a study to determine the efficiency of hatchery-reared brown trout in a stream stocking program. This project has been established as a cooperative program between The Fish and Wildlife Service, Cornell University and the State of New York. The role of this laboratory and hatchery is to rear brown trout under various conditions for stocking and to follow the progress of the fish by means of chemical analyses after they are placed in the stream. Cornell University and the State of New York carry the responsibility for the field work including management studies, creel census work and estimation of total population by means of electrical shocking.

It is hoped that the chemical studies upon the fish will shed some light upon the physiological changes that trout go through after being placed in a stream. From these studies it may be possible to produce a better trout by applying the information so obtained.

This past season two lots of fish were planted that had been reared on the same diet for one year (the standard No. 6 mixture of this hatchery) but held at two different water temperatures. One group was held at a temperature of 47°F whereas the other group was held in the production supply of this hatchery whose temperature varies from 39°F in the winter to about 60°F in the summer. This meant that the group held in the normal hatchery water grew at a more rapid rate than did those held in the colder water. Thus there was a retarding action upon the fish that was governed by the temperature of the water.

Since these fish were fed according to the standard feeding tables for trout (Deuel et al, 1942), the fish in the 47°F water were alloted a reduced food intake in comparison to the other lot of fish, particularly during the summer months when the water used in the production unit was considerably higher than 47°F. The water temperature itself produced a calorie stunting effect upon the fish held in the colder water by reducing the food intake of the fish. At the time of stocking, those fish that were so retarded averaged 19.6 grams in weight, whereas those that were held in our production water supply averaged 80.3 grams.

After a period of one month, a census was taken by means of electric shocking in the stream by the field crew and samples of the two lots of fish were removed for analyses. This has been termed the spring analyses. In the fall a second census was made and a second sample of the two groups removed for analytical purposes. This is called the fall analyses. At the time of the stream census, fish from the two groups that still remained in the hatchery were also prepared for analyses for comparison with the stream fish.

No data will be given upon the results of the stream body in relation to survival since a separate report will be made by Cornell University and the State of New York upon this phase. All stocking was carried on in Fall Creek, a tributary to Cayuga Lake, located about eight miles from the City of Cortland, New York.

The data have been summarized in Tables 10 and 11. Table 10 lists the analyses of the dehydrated trout whereas Table 11 shows the conversion of the data to a wet basis. The data are shown graphically in Chart 3. All data were tested by means of analysis of variance.

BLE 10. **Chemical composition of brown trout before and after stream stocking 1/**

Group	Percent fat	Iodine number	Percent protein	Percent ash	Percent water	Average weight of fish grams
		Spring analyses				
Retarded hatchery 2/	13.1	100.4	71.8	11.3	77.3	19.6
Normal hatchery 3/	25.6	83.4	68.4	8.6	73.8	80.3
Retarded stream	10.6	121.3	70.0	12.7	78.1	27.1
Normal stream	20.1	107.3	68.7	10.3	75.4	70.4
		Fall analyses				
Retarded hatchery	20.0	110.4	62.3	8.9	75.7	40.0
Normal hatchery	22.5	99.2	61.3	8.1	74.1	100.0
Retarded stream	7.8	145.5	60.8	15.8	77.3	55.7
Normal stream	8.9	126.1	68.6	11.9	78.4	106.0

1/ Analyses expressed in relation to the dry weight of the trout.

2/ Retarded fish - trout reared at a temperature of 47°F throughout their hatchery life.

3/ Normal fish - trout reared at a temperature varying with the season from a low of about 39°F to a high of about 62°F.

WATER CONTENT

There was a significant difference in the water content of the trout held under the two hatchery conditions. At both times of the analyses the retarded fish contained a significantly higher amount of water. However, these differences are small and perhaps reflect more of a difference in fish size than conditions under which they were grown. It was also found that the stream fish contained more water than the fish held in the hatchery. This was apparent even after only one month in wild waters. By the time of the second series of analyses there was no difference between the retarded and normally grown trout that had been in the stream.

TABLE 11. Chemical composition of brown trout before and after stream stocking 1

Group	Percent fat	Iodine number	Percent protein	Percent ash	Percent water
			Spring analyses		
Retarded hatchery 2/	2.9	100.4	16.3	2.6	77.3
Normal hatchery 3/	6.7	83.4	17.9	2.2	73.8
Retarded stream	2.3	121.3	15.4	2.8	78.1
Normal stream	4.9	107.3	16.8	2.5	75.4
			Fall analyses		
Retarded hatchery	4.9	110.4	15.2	2.2	75.7
Normal hatchery	5.8	99.2	15.9	2.1	74.1
Retarded stream	1.8	145.5	13.8	3.6	77.3
Normal stream	1.9	126.1	14.8	2.6	78.4

1/ Analyses expressed in relation to original wet weight of trout.

2/ Retarded fish - trout reared at a temperature of 47°F during their hatchery life.

3/ Normal fish - trout reared at temperature varying with the season from a low of about 39°F to a high of about 62°F.

FAT CONTENT

The comparison of the fat content of the two groups of fish was most outstanding and the changes observed after planting were quite marked. At the time of the spring analyses the normal trout showed about twice the fat content of the retarded group. By the time of the fall analyses those fish that were still in the hatchery showed no difference in fat content between these two groups. It would therefore appear that in the hatchery the fat content is a function of size rather than rapidity of growth. The normally grown or larger fish showed but little change during the period between spring and fall but the retarded trout produced a significantly gain in their fat content. During this same period the small fish more than doubled their weight, whereas the larger fish showed a gain of only 25 percent.

The drop in fat content of both the retarded and normal trout after stocking was outstanding. Even after a period of only one month, the drop was noticeable and by the time of the fall census (approximately four months in the stream) the drop was not only drastic but there was no difference between the retarded and normal fish.

IODINE NUMBER

In addition to the total content of the body fat of these trout, iodine numbers were run to determine the change in character of the fat after stocking. Again there was an outstanding difference in the iodine number of the fat after the fish had been placed in the stream. After only one month in the stream there was a marked increase in the iodine number of the plantedtrout and by the time of the fall census this had reached a still higher level. Thus it is shown that as the trout fed on the natural food of the stream, his body fat definitely changed in character to a much softer fat.

Both the spring and the fall analyses showed that the retarded fish held in the hatchery produced fat with a higher iodine number than the normal group. The only possible explanation that is known for this would be that the fish held in the colder water would use less of the harder fats of the diet and hence produce a softer fat in the body. In general,the values for thesefish are much lower than is generally found for fish oils. However, since the body fat tends to show the characteristics of the food fat, such results as these are not too unexpected. In general, the fats of our hatchery foods tend toward the harder side and hence would effect the body fat of the fish.

Such changes in iodine numbers indicate a great change in the character of the body fat of the fish and show a difference in stream food.

It should be recognized that such changes as these are dependent upon the food supply of the stream which of course will vary from one body of water to another. Nevertheless it should also be pointed out that the character of the fat of the fish after being planted was much nearer the values usually associated with fish oils and those values found for hatchery fish are extremely low.

PROTEIN CONTENT

The protein content of the various groups showed the least variation of the variables studied. The smaller retarded fish contained less protein than did the larger, normally grown trout. This is particularly evident when the analyses are converted to a wet basis (Table 11). In all cases, the spring analyzed fish showed a higher protein content than did the fall series (Table 11). When the analyses are compared on a dry basis(Table 10)the reverse results are seen. A comparison of the water content of the various groups (Table 10) will show this to be the affective variable.

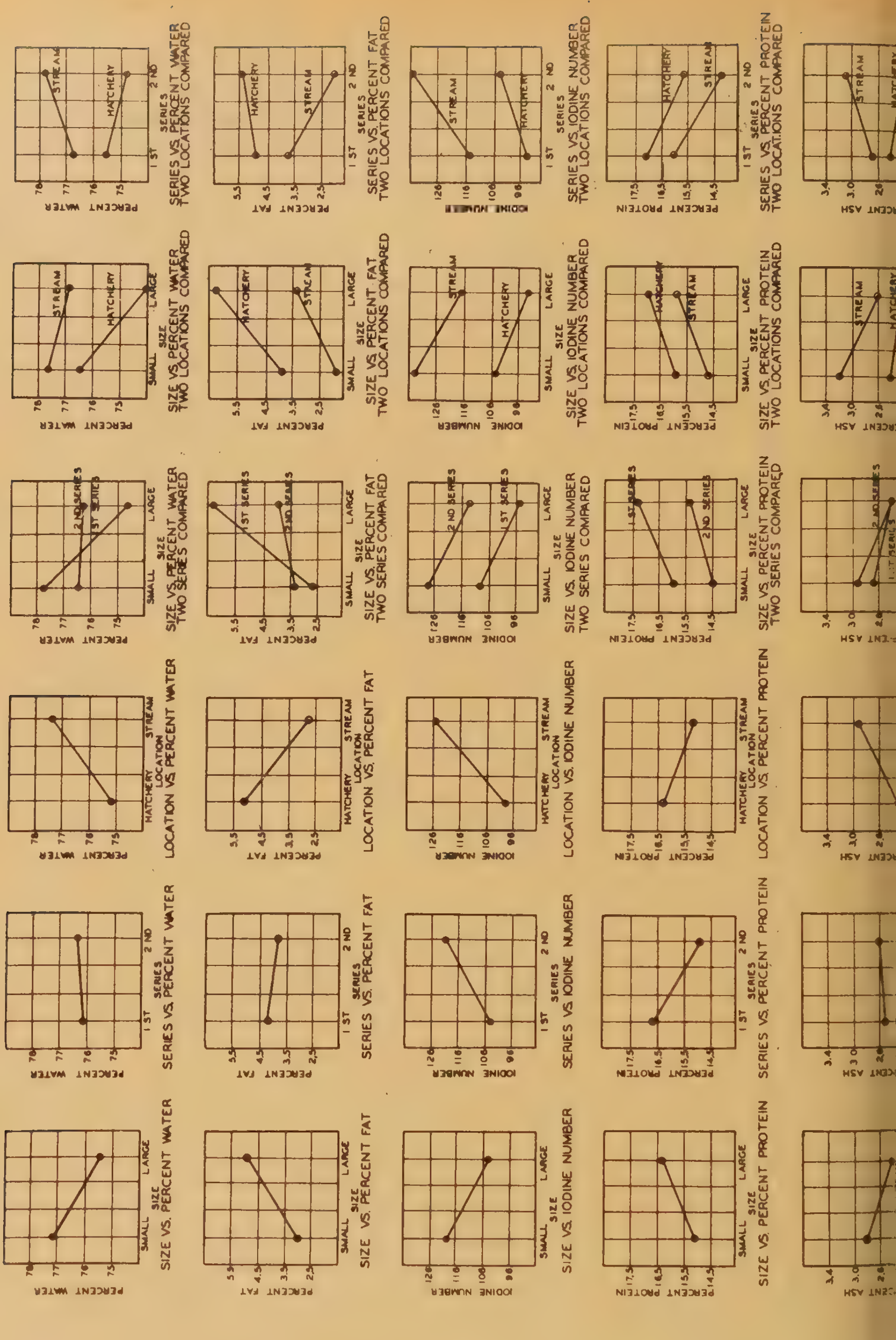


Chart 3. Graphic description chemical composition of brown trout before and after stream stocking.

ASH CONTENT

The minerals in the body were present in larger amounts after the fish were planted and this was quite evident after only one month in the stream. The apparent differences among the other groups are small although in most cases significant.

GENERAL DISCUSSION

The most marked changes found in the fish after planting were the reduction in total body fat and the drastic change in the character of the fat, as indicated by iodine number. Both of these factors indicate a change in the character of the food of the fish in the stream as compared to the hatchery diet.

Changes in protein and ash were much less spectacular but do indicate that the fish undergoes minor changes in these body components.

Preliminary studies such as these have not given a basis for specific suggestions on the improvement of hatchery fish for stocking. It should also be realized that the changes that occurred in the fish planted in Fall Creek do not of necessity mean that such changes will also occur in all bodies of wild waters. However, it has given a small insight to some of the things that may take place and future studies may give us specifications as to what a hatchery trout should be on a chemical basis.

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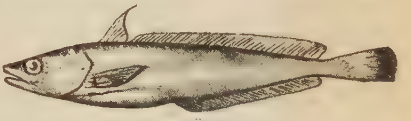
THE TRASH FISHERY OF SOUTHERN NEW ENGLAND IN 1950[1]

By Richard E. Sayles*

GROWTH OF THE FISHERY

Greatly increased landings of "trash fish" (species formerly discarded during trawling operations) at New England ports during 1949 caused concern because of their possible effect on the existing fisheries in the area, especially since there were rumors that large numbers of young haddock, cod, and flounders were included in these trash landings. With the continuing growth of the trash fishery during 1950, the U. S. Fish and Wildlife Service began a systematic sampling of the landings, so as to obtain an estimate of the quantities contributed by each of the several species landed at southern New England ports during that year.


RED HAKE (UROPHYCIS CHUSS) IS ONE OF THE LEADING SPECIES INCLUDED IN NEW ENGLAND TRASH FISH LANDINGS AND COMPOSES 28.9 PERCENT OF THE TOTAL.

As reported by Snow (1950), trash fish had been landed in small amounts prior to 1949 for use as mink food. The increased use of fish meal in poultry and hog feeds led to an expanded demand by reduction plant operators for raw material to augment that afforded by the existing production from menhaden, cannery waste, and offal. This situation, together with the fact that flounder fishing (the mainstay of the small draggers) was poor, led fishermen to land trash fish in ever-increasing quantities.

If this new and growing fishery were dependent in a measurable part on the young of important edible species, it might adversely affect the established fisheries. However, this concept can be accepted only if the mortalities between juvenile and adult stages were proved to be low, and if the advantage to the marketable species in having their competitors and predators removed were disregarded.

TOTAL LANDINGS

Landings of trash fish at southern New England ports totaled 90.3 million pounds (table 1) during 1950, an increase of 20.1 percent over the 1949 landings of 75.2 million pounds. This rise, while not as large as that of the previous year when trash fishing commenced, indicates that the market for trash fish in this area is being maintained.

New Bedford was again the leading port with 56 million pounds, or 62.1 percent of the total. Landings at all southern New England ports increased steadily during the first five months, to a peak of 15.8 million pounds in May. Then, during the last week in that month, the price offered by dealers at New Bedford was reduced from $20 to $15 a ton. Similar reductions took place at other ports, resulting in a steady decrease in trash landings for the last six months of 1950 at all ports, as fishermen concentrated on more profitable species. Landings at all ports for November were only 2.2 million pounds. Thus, while the total poundage exceeded that of

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[1] PREPARED AT THE REQUEST OF THE ATLANTIC STATES MARINE FISHERIES COMMISSION. THE FISH AND WILDLIFE SERVICE IS THE STATUTORY RESEARCH AGENCY OF THE COMMISSION.

* FISHERY AID, BRANCH OF FISHERY BIOLOGY, U. S. FISH AND WILDLIFE SERVICE, DEPARTMENT OF THE INTERIOR.

1949, the trend during the latter part of the year was a reversal of the steady increases reported from March 1949 to May 1950.

Table 1 - Southern New England Trash Fish Landings, 1949-50 1/

Locality	1950 Thousands of lbs.	1950 Percentage of Total	1949 2/ Thousands of lbs.	1949 2/ Percentage of Total
New Bedford, Mass.	56,041	62.1	44,115	58.6
Gloucester, Mass.	14,183	15.7	14,567	19.4
Provincetown, Mass. 2/	5,542	6.2	2,234	3.0
Boston, Mass.	393	0.4	-	-
Point Judith, R. I.	9,404	10.4	9,989	13.3
Stonington, Conn.	4,735	5.2	4,290	5.7
Total	90,298	100.0	75,195	100.0

1/ FOR REDUCTION AND ANIMAL FOOD. ALTHOUGH THESE FIGURES COVER ONLY THE PORTS INDICATED, THEY PROBABLY ARE VERY CLOSE TO THE TOTAL NEW ENGLAND LANDINGS FOR THESE YEARS. NOT INCLUDED ARE LANDINGS IN MAINE, BUT THE SEA HERRING LANDED IN THAT STATE (ALTHOUGH SOLD FOR REDUCTION PURPOSES IN SOME CASES) IS NOT CONSIDERED A "TRASH FISH" AND THE LANDINGS OF OTHER SPECIES THAT COULD BE INDICATED AS "TRASH FISH" ARE NEGLIGIBLE.
2/ LANDINGS AT MINOR CAPE COD PORTS INCLUDED.

SPECIES COMPOSITION OF THE LANDINGS

I examined samples of the landings at Provincetown and at New Bedford in Massachusetts and at Point Judith in Rhode Island.

Thirteen catches were sampled at New Bedford, 5 at Provincetown, and 4 at Poin Judith by examining several baskets of fish as unloading progressed. Sorting each sample by species, and recording th number of species and the weight o each sample, it was found that the samples taken weighed from 100 to 500 pounds, depending on the size c the load and on the amount of time available to return the fish in tim to be loaded on the truck. Fishermen and dealers gave excellent cooperation during all sampling operations.

The practice of taking basket at intervals during the unloading of a vessel revealed, for the most part, that the same species appeare in successive baskets, but the rel tive numbers of a given species vari considerably between baskets compr ing the sample. The species comp sition indicated by a given sample therefore, is a reliable index of composition of a vessel's load, bu the relative numbers of each speci determined by combining the number in each basket, are at best only rough estimates of the actual numbers of each species present in th load. Thus, the species compositi

Table 2 - Species Composition (Estimated) of the 1950 Trash Fish Landings at Provincetown and New Bedford, Mass., and Point Judith, R. I.

Species Composition	Thousands of lbs.	Percentage of Total
Principal Species:		
Red hake	21,903	28.9
Eel pout	15,916	21.0
Skates	11,520	15.2
Whiting	8,185	10.8
Long horn sculpin ..	6,973	9.2
Goosefish	4,699	6.2
Butterfish	2,350	3.1
Daylight flounder ..	1,364	1.8
Yellowtail " ..	834	1.1
Other food species 1/	1,137	1.5
Other trash species 2/	909	1.2
Total	75,790	100.0

1/ INCLUDE: DABS, BLACKBACK FLOUNDER, FLUKE, HADDOCK, COD, WHITE HAKE, SEA BASS, SEA HERRING, HICKORY SHAD, ALEWIVES, AND SCUP.
2/ INCLUDE: TOADFISH, SHORT HORN SCULPIN, SEA RAVEN, SPINY DOGFISH, SEA ROBIN, FOUR-SPOTTED FLOUNDER, AND INVERTEBRATES.

of the landings from Provincetown to Stonington, as shown in table 2, may be regarded as reliable for species present, but the poundages shown are only an estimate of the true quantities.

It will be noted in table 2 that red hake was the predominant species, with eel pout and skates following in that order. Of the important edible species, whiting were landed in the greatest numbers, comprising 10.8 percent by weight of the trash fish landed in ports where catches were sampled.

New Bedford landings included only small quantities of such edible species as yellowtail and blackback flounder, dab, butterfish, scup, haddock, and cod. Percentages of these species ranged from 1 to 4 percent by weight, except for one sample which contained 9.2 percent yellowtail flounder.

At Provincetown, yellowtail flounder was the only important edible species appearing in large numbers. Three samples contained by weight 11, 14, and 23 percent, respectively, yellowtail flounder. Other edible species, such as blackback flounder, cod, and haddock ranged from less than 1 percent to a maximum of 4 percent.

At Point Judith, one sample contained 40 percent butterfish. Other samples at this port yielded less than 1 percent of blackback flounder, scup, and fluke.

ONE OF THE SKATES INCLUDED IN THE NEW ENGLAND TRASH FISH LANDINGS. ALL SKATES COMPOSE ABOUT 15.2 PERCENT OF THE TOTAL. THIS PARTICULAR SPECIES IS THE BARNDOOR SKATE (RAJA LAEVIS).

Conversations with fishermen during field trips indicated landings of small yellowtail flounders at Provincetown in greater numbers than were observed in the samples examined at that port. Other reports dealt with landings of small butterfish at Sandwich, Massachusetts, and at Point Judith, Rhode Island. I was unable to confirm the Sandwich report. One vessel's catch at Point Judith, as mentioned earlier, contained 40 percent butterfish by weight. Such reports often become exaggerated and the fishermen, with few exceptions, are conservation-minded enough to try to avoid taking trash fish in areas known to contain large numbers of the young of important edible species. Therefore, the unconfirmed reports cannot be accepted as seriously affecting the estimate of landings by species which appears in table 2.

SUMMARY AND CONCLUSIONS

The 1950 trash fish landings for southern New England were 90.3 million pounds. While greater than the 1949 landings of 75.2 million pounds, a reversal of the 1949

WHITING (MERLUCCIUS BILINEARIS) ALTHOUGH INCLUDED IN NEW ENGLAND TRASH LANDINGS, COMPOSES ONLY ABOUT 10.8 PERCENT OF THE TOTAL

trend was indicated when landings decreased steadily during the latter half of the year.

Fifty-six million pounds or 62.1 percent of the landings were made at New Bedford, while in 1949 only 58.6 percent or 44 million pounds of the total landings were reported at that port.

Sampling of the landings at Provincetown and New Bedford, Mass., and at Point Judith, R. I., showed that red hake comprised 29 percent, eelpout, 21 percent and skates 15 percent of the total.

New Bedford, with the bulk of the landings, showed the smallest percentage of important edible species. One sample contained 9.2 percent yellowtail flounder. Others yielded from 1 to 4 percent yellowtail and blackback flounder, dabs, haddock, cod, butterfish, and scup. Thus, the New Bedford samples failed to show appreciable quantities of young or mature individuals of the important edible species.

ANGLERFISH OR GOOSEFISH (LOPHIUS PISCATORIUS) IS ALSO INCLUDED IN THE NEW ENGLAND TRASH FISH LANDINGS, BUT THIS SPECIES COMPOSES ONLY 6.2 PERCENT OF THE TOTAL CATCH.

Three of the four samples taken at Provincetown showed 11, 14, and 23 percent, respectively, of yellowtail flounder, with 1 to 4 percent of blackback flounder, dabs, cod, white hake, butterfish, and pollock.

On the basis of the samples taken, it appears that the New Bedford fleet is not exploiting the young or mature individuals of the important edible species to any appreciable extent. On the other hand, large numbers of small yellowtail flounders were landed at Provincetown, and at least one load of small butterfish was landed at Point Judith, Rhode Island. One sample at Point Judith contained 40 percent butterfish; others showed small quantities (less than 1 percent) of blackback flounder, scup, and fluke.

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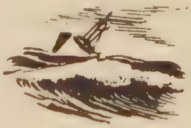

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FISH AND SHELLFISH MEASURING DEVICES

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A great many investigators in the field of fishery biology are concerned with studies of marine or fresh-water populations of fish or shellfish and, consequently, much of their effort is devoted to acquiring a knowledge of the age, growth and racial characteristics of the species involved. Information on these problems is largely obtained from measurements of the various parts of the bodies of the organisms. Differences between the age, growth and morphological characters of various populations or races of a species are often small; therefore, it is usually necessary to employ relatively large masses of data to establish whether or not a significant dissimilarity exists. Because of the need for measuring large numbers of individuals, fishery biologists have devised a number of instruments which enable them to collect linear measurements in both an accurate and facile manner.

I have been prompted to discuss this matter of measuring fish and shellfish by the reading of an article by Hiatt and Hamre (1945) in which a description is given of a measuring device which has been used in an improved form by fisheries men both on this continent and in Europe for many years.

It is, of course, always difficult to determine the original inventor of any device. Many ingenious devices have no doubt been used for specific problems, but have never been described in the literature. As a rule, emphasis is placed on the results of the observations and experiments rather than on the exact means by which the data were measured.

Recently, how to measure the length of a fish has been thoroughly discussed by Ricker and Merriman (1945) and Hile (1948). These authors have listed eleven methods of measuring fish lengths. Of these eleven, three refer to total lengths measured from the anterior end of the fish (this point usually being the tip of the jaw) to the extreme points of various parts of the tail fin. The measuring of total length can be readily and accurately effected by a simple board with a "head stop" and a graduated rule. The method of recording on celluloid sheets the total lengths by perforations at the point of measurement, as mentioned by Buchanan-Wollaston (1928) and Thompson (1929) is advantageous when one is interested in securing length frequencies of the populations. The other eight measurements are "standard" lengths, which involve distances between the anterior end of the fish and various anatomical structures located short of the posterior end of the fish. The determination of any of these eight measurements is greatly assisted by the use of special devices similar to that of Hiatt and Hamre. "Standard" lengths are commonly used for determining the length of herring and sardines, because the tails of those species are often damaged in the commercial fishery.

Williamson (1900) satisfied his own need for a rapid and accurate method of obtaining various body measurements on the mackerel, such as between the tip of the jaw and the end of the operculum, the tip of the jaw and the anterior insertion of the dorsal fin, etc. His device measured these distances in a plane parallel to the axis of the body of the fish, as does that of Hiatt and Hamre. Williamson (1914) used this measuring board also on the herring. As this apparatus was rather primitive and has been succeeded by more durable and efficient modifications, there is no need of describing it in detail here.

Riddell (1914) described an improved version of Williamson's board and his apparatus closely resembles the models used by the herring and sardine investigators in Canada and the United States. In altering Williamson's device, Riddell, among other changes in design, substituted a cross wire for a cross thread and brass moving parts for wooden ones. The measuring boards described by Thompson (1917, 1926) and Rounsefell (1930) are basically similar to the Riddell board.

These boards operated on the same general principle as that of Williamson's, but each improved model was more durable and more easily operated. These devices are adequately described in the above references. During a recent investigation of the Maine herring, a board patterned basically on Rounsefell's design, but with a base of Lucite instead of brass on wood and with the cross wire in intimate contact with the millimeter scale to eliminate the use of a mirror for the reduction of parallactic effect, gave excellent service.

While boards similar to the Riddell model and the subsequent slight modifications have been satisfactory in most instances, there have been several investigators who have felt the need for more radical alterations in its design. Hart (1936) felt that these types of boards could be improved to eliminate the eyestrain which often occurs when one uses the boards for a considerable period of time. It is necessary before reading the scale to align the cross wire, the image of the cross wire in the mirror, and the point on the fish. Hart's device eliminated the need for a mirror, but the apparatus had somewhat more complicated moving parts and is not in common usage, to my knowledge. Sette (1941) noted that digit bias was prevalent among his colleagues who measured sardines with a modification of the board used by Riddell. To eliminate such bias, he incorporated in the measuring mechanism a mechanical selector which relieved the user of the responsibility of selecting, by eye, the nearest millimeter.

There is one method by which the digit bias could be considerably reduced without the use of Sette's mechanical selector. The measurer can consider each distance between the millimeter marks as a single unit, rather than determine whether the measurement which falls nearly half way between the

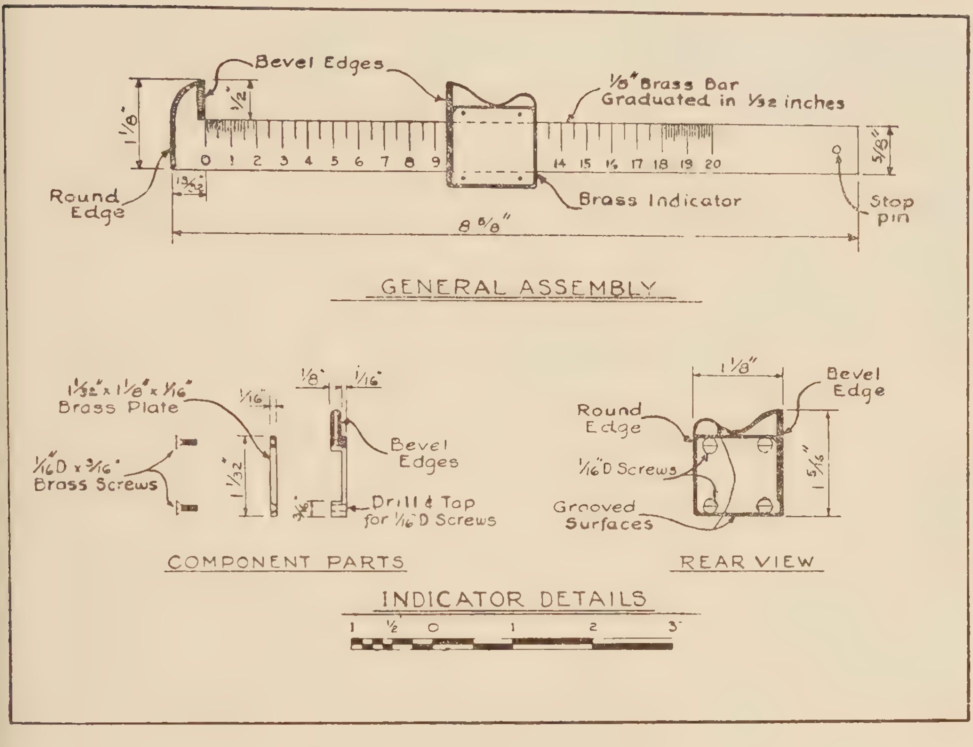

FIG. 1. Lobster measuring caliper.

two millimeter graduations should be credited to the lower or higher millimeter value. For example, when a fish is 52.49 millimeters long, it is rather difficult to decide whether it should be recorded as 52 or 53 millimeters and digit bias may have its influence on decisions of this kind. If one considers any measurement falling between 52 and 53 millimeters as 52 millimeters, then trouble of this nature is not so prevalent, although there is still some difficulty in deciding whether the fish measures less or greater than the millimeter mark. However, at least in this case there is a definite mark to indicate the boundary of the millimeter intervals. Then, for example, the actual value of the recorded number 52 is 52.5 (range 52.00 to 52.99), instead of the usually understood value 52.0 (range 51.50 to 52.49). This fact must be borne in mind in later analyses of the data. Scales which are offset one-half or one and one-half graduations are often used, so that one measures only between the graduations, but still retains the common mean value and range.

During recent years, I have employed a caliper device which was originally planned for measuring the lengths of lobsters, but was later also used for other invertebrates, including mollusks. When measuring lobsters, one determines the straight line distance between the posterior margin of the eyesocket and the posterior end of the carapace. Maximum and minimum size regulations in United States lobster-producing states are based principally on this type of carapace measurement. Size regulations concerned with total lengths as measured from the tip of the rostrum to the end of the tail were generally unsatisfactory because evaders of the law could break off the rostra to decrease the total lengths or increase the lengths by stretching the membranes between the tail segments and between the junction of the tail and carapace.

The first caliper which I devised for use in measuring lobsters was one built from celluloid and graduated in millimeters. This proved to be fairly satisfactory, but had two principal drawbacks. First, it did not withstand hard usage in the field and, second, there was no particular need for measuring and recording the lobster sizes in millimeters when all size regulations were already based on the English system of inches. I was unable to find any suitable commercial caliper for my use, so I designed a model of simple and rugged construction which has proven satisfactory to all who have used it since 1941. Figure 1 illustrates the latest model, built entirely of hard brass. I am fully aware that many such caliper devices have been probably used in the past, but nevertheless, I present this apparatus with the hope that others may also be able to utilize it profitably.

As can be noted from the figure, the graduations mark thirty-seconds of an inch and are grouped in tens. For brevity, 10 on the scale is represented by the numeral 1, and 20 by 2, etc. The graduations by tens of thirty-seconds facilitate rapid reading of the scale because of the elimination of the usual half, quarter, eighth, sixteenth, and thirty-second units so often seen on rulers. It was found desirable to measure lobsters in thirty-seconds of inches, but in other cases it might be accurate enough to measure in larger units as sixteenths or eighths. Whatever unit of the English system is used, it is an advantage to have the units grouped in tens.

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Reprinted from Copeia, 1951, No. 2, June 8

THE OCCURRENCE OF EGG CAPSULES IN THE WINTER SKATE (*RAJA DIAPHANES*) IN MAINE WATERS.—In 1949, Maine fishermen landed large quantities of spiny dogfish and skates, which were used for fish meal. The opportunity to examine some of the skates was provided me by the Maine Fish Meal Company of Portland, Maine. I inspected the entire catches of several line-trawl boats on September 6 and 13. Among a total of 81 skates, I found there were 25 male and 42 female *Raja stabuliforis,* 2 male and 3 female *R. scabrata,* 3 male and 2 female *R. erinacea,* and 2 male and 2 female *R. diaphanes.* These last-mentioned 2 females, measuring 751 and 763 mm. total length, each contained one egg capsule. None of the females of the other species, however, contained egg capsules.

Bigelow and Welsh (1925, Bull. U. S. Bur. Fish., 40 (1): 62) stated that the breeding habits of *R. diaphanes* in the Gulf of Maine have not been traced. Vladykov (1936, Le Nat. Can., 63: 211–231) declared that the breeding season of this species in Canadian Atlantic waters takes place in September. My observations indicate that during September this species also spawns in waters along the Maine coast.—Leslie W. Scattergood, *U. S. Fish and Wildlife Service, Boothbay Harbor, Maine.*

Reprinted from COPEIA, 1951, No. 1, March 21

NOTES ON THE SIZE OF MENHADEN TAKEN IN MAINE DURING 1949.—During 1949, over 5,000,000 pounds of menhaden, *Brevoortia tyrannus* (Latrobe), were caught off the Maine coast, compared to 145,000 pounds in 1948 and 14,000 pounds in 1947. The revival of this fishery after a lapse of twenty years enabled us to collect some original data on the size and maturity of this species.

We obtained five samples of menhaden during the 1949 season, but we were unable to determine the sex in two samples because of decomposition. The other three samples were suitable for sex determination, and from them we obtained the data on male and female lengths (standard lengths from the tip of the lower jaw to the posterior end of the scale row, in millimeters) as shown in Table I. To change this standard length to the length measurement from tip of lower jaw to fork of the caudal fin, a conversion factor of 1.0459 can be employed. A *t* test of the lengths of the two sexes shows that in each sample a significant difference exists between the male and female menhaden lengths, for the *P* value in each case is less than 0.01.

The lengths of all the fish in each of the five samples are compared as shown in Table II. By means of the *t* test, we have compared the lengths of the fish in each sample with those of each of the other four samples. The lengths of the fish in the Boothbay Harbor sample are significantly larger than those of the other four samples, for the *P* value is less than 0.01 in each of the four comparisons. Comparisons of the lengths of the fish in the four other samples show no significant difference between samples. The large size of the fish has always been characteristic of the schools of menhaden occurring in the Gulf of Maine (Hildebrand, 1948, Smith. Misc. Coll., 107 (18): 10).

TABLE I

		Males				Females			
Date	Locality	Number	Range	Mean	σ*	Number	Range	Mean	σ*
Aug. 4	Boothbay Hbr., Me.	29	300–329	315.2	8.21	71	304–357	325.3	9.44
Sept. 7	Casco Bay, Me.	35	291–322	311.4	7.27	65	296–349	319.6	11.77
Sept. 14	Barnstable, Mass.	40	272–325	309.0	10.16	60	283–353	321.2	13.16

* σ = standard deviation

TABLE II

Date	Locality	Number	Range	Mean	σ*
July 19	Casco Bay, Me.	100	291–342	316.7	10.61
July 29	—do—	100	295–352	317.9	9.92
Aug. 4	Boothbay Hbr., Me.	100	300–357	322.4	10.17
Sept. 7	Casco Bay, Me.	100	291–349	316.7	10.80
Sept. 14	Barnstable, Mass.	100	272–353	316.3	13.67

* σ = standard deviation

Some observations were also made of the sexual condition of the female fish. In the August 4 sample, 20 of the 71 females had already spawned, while the other 51 had well developed ovaries. The September 7 sample had 50 spawned-out females, 11 with large ovaries and 4 with undeveloped ovaries. The September 14 sample had 37 spawned-out females, 20 with fully developed ovaries containing dead eggs, and 2 with undeveloped ovaries. No males or females were seen with the sex products in the "running" condition. Fishermen reported that spawning occurred during the summer in Casco Bay, but we cannot verify their statements.

Our capture of small menhaden in a herring weir in the Sheepscot River during December 5, 6, 9, and 11 may be evidence that spawning occurred in Maine waters. Forty-three fish ranged in length from 52 to 95 mm., with a mean of 77.3 mm. and a standard deviation of the mean of 11.71 mm. Several other small fish were seen on December 31 in another Sheepscot weir. These small menhaden were living in waters with temperatures of 40 to 46 degrees. The fate of these small fish, with the advent of colder water, is problematical. Those in Maine waters during the winter may perish; however, it is possible that most of the young ones may have returned to more southern waters.

If spawning is successful, will an independent population of menhaden be established in Maine waters, or will the fishery always have to rely, as in the past, on the sporadic migrations of the large mature fish from the south? There are no answers to these questions. Our knowledge of the biology and habits of this species is extremely meager, even though it is the most important, in terms of poundage, of all the commercial species on the Atlantic coast of North America.—LESLIE W. SCATTERGOOD and PARKER S. TREFETHEN, *U. S. Fish and Wildlife Service,* and GARETH W. COFFIN, *Maine Sardine Packers Association, Boothbay Harbor, Maine.*

Reprinted from Copeia, 1951, No. 2, June 8

NEW GULF OF MAINE RECORD FOR OCCURRENCE OF DOLPHIN, *CORYPHAENA HIPPURUS*, AND DATA ON SMALL SPECIMENS.—What is believed to be a new record for the occurrence of dolphin, *Coryphaena hippurus* (Linnaeus), in the Gulf of Maine, is herein recorded with the capture of one near Provincetown, Mass., on August 10, 1949. This fish was taken in a trap set by the Pond Village Cold Storage Company at North Truro, on the Massachusetts Bay side of Cape Cod. Collected by Mr. John Worthington, it was 435 millimeters long (fork length) and weighed 1 pound, 13 ounces.

Prior to 1949, I can find no recorded capture of dolphin in the Gulf of Maine, although there are at least two authenticated records of the occurrence of dolphin off Nova Scotia. (I am indebted to Dr. L. R. Day of the Fisheries Research Board of Canada for locating these Nova Scotia records).

In the summer of 1949, large numbers were taken off Martha's Vineyard (where occasional stragglers have been taken in other years), beginning on July 30 and 31, when Mr. Frank Mather and party, of the Woods Hole Oceanographic Institution, boated 25, the largest weighing 23 pounds. A northward continuation of this unusual distribution seems to account for the capture of the specimen near Provincetown, Mass., which is more than 50 miles farther to the north and lies inside of Cape Cod Bay. Their presence in these waters in 1949 was probably due to the very warm weather which apparently increased water temperatures in this area to limits tolerable to the species (Arnold, 1951 Copeia (1): 87–88).

A recent paper by me (1951, Copeia (1): 35–39) included the length-weight relationship of dolphin. However, when this relationship was computed, no data for small fish were available. During this unusual northern appearance I succeeded in collecting 23 small specimens, in cooperation with Mr. Frank Mather; the fork lengths in mm., followed by the weights (in pounds) in parentheses are 372 (1.06), 376 (1.06), 377 (1.00), 380 (1.12), 383 (1.12), 388 (1.00), 388 (1.19), 390 (1.38), 391 (1.12), 391 (1.25), 395 (1.25), 395 (1.38), 400 (1.19), 400 (1.25), 401 (1.44), 405 (1.44), 410 (1.56), 425 (1.56), 430 (1.62), 430 (1.69), 437 (1.69), 438 (1.69), and 455 (2.25).—Howard A. Schuck, *U. S. Fish and Wildlife Service, Woods Hole, Massachusetts.*

Reprinted from Copeia, 1951, No. 1, March 21

NORTHERN RECORD FOR THE LITTLE TUNA, *EUTHYNNUS ALLETTERATUS*.—A new northern record for the occurrence of little tuna (little tunny, false albacore), *Euthynnus alletteratus* (Rafinesque), is believed to be registered with the capture of 28 of these fish, weighing a total of 390 pounds, on September 11, 1949, in Cape Cod Bay, Massachusetts. These fish were taken in a trap operated by Mr. B. Harlow Morrow near Sandwich, Massachusetts.

Previous to this capture there was no record of the little tuna north of the Cape Cod Peninsula, which apparently acted as a barrier to this fish, as well as to many other southern species. Bigelow and Welsh (1925, Bull. U. S. Bur. Fish., 40 (1): 211) did not record the little tuna and referred to the species only as ". . . a fish to be expected, though not yet actually recorded, in the Gulf of Maine." Breder (1948, Field Book of Marine Fishes of the Atlantic Coast from Labrador to Texas: 125) listed its range as "Cosmopolitan in warm seas occasionally north to Cape Cod. . . ." LaMonte (1946, North American Game Fishes: 25) gave the range as "North to Cape Cod, Massachusetts; rather common off New York in summer and fall." Fraser-Brunner (1949, Ann. and Mag. Nat. Hist., Ser. 12, 2: 626–27) has recognized two subspecies: *E. a. alletteratus* (Rafinesque) from the North Atlantic and the Mediterranean and *E. a. aurolitoralis* Fraser-Brunner from the Gold Coast, West Africa.—Howard A. Schuck, *U. S. Fish and Wildlife Service, Woods Hole, Massachusetts.*

Reprinted from COPEIA, 1951, No. 1, March 21

Notes on the Dolphin (*Coryphaena hippurus*) in North Carolina Waters

By Howard A. Schuck

DURING cruises of the U. S. Fish and Wildlife Service's research vessel "Albatross III" in waters off North Carolina, an opportunity was afforded to collect dolphin (*Coryphaena hippurus*) and to record certain data concerning them. This species, also called dorado, was taken incidental to the main work of investigating the bottom fisheries of this area.[1] Although the number of specimens is small, it is thought that, considering the lack of biological information on this species, the data collected are of sufficient value to report.

METHOD OF COLLECTING DATA.—During much of the three weeks (May 19 to June 14, 1949) that the "Albatross III" was investigating the fishery off North Carolina, three lines with artificial lures (feather jigs) were trolled on the surface at a speed of about eleven knots, while en route to various stations. This trolling yielded the 19 specimens reported upon herewith.

The data collected for each fish were: length, weight, sex, and stage of maturity. In addition, gonads of females were preserved and notes were taken on stomach contents. Depth of water and the place of capture were also recorded for each specimen.

DISTRIBUTION.—The surface waters, which were trolled, ranged from areas as shallow as one fathom, near shore, to areas over 1,000 fathoms deep, well out into the Gulf Stream, and were between latitude 32°00′ N. and latitude 36°00′ N. This area includes most of the waters off the coast of North Carolina.

In addition to recording the locality of capture, the location where each dolphin was hooked but lost was also recorded. Other species were lost in smaller numbers, but most of the dolphin that were lost were distinguishable from other species. The latter included bonito (*Sarda sarda*); little tuna, false albacore, or little bonito (*Euthynnus alletteratus*); amberjack (*Seriola dumerili*); and what was tentatively identified as a blackfin tuna (*Parathunnus atlanticus*).

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[1] These studies were undertaken jointly by the Institute of Fisheries Research of the University of North Carolina and the Fish and Wildlife Service of the U. S. Department of the Interior. This report appears by permission of both organizations.

The miles that were trolled on the surface (by three lines) in each of the various depth zones, as well as the number of dolphin caught, the number of fish thought to be dolphin that were hooked and lost, and the average number of miles per fish hooked, are shown in Table I. It can be seen that a considerable difference exists in the relative success of trolling over the different depth zones; it was most productive over the range of 21 to 100 fathoms, relatively unproductive over shoal water and the 101-1,000 fathom layer, and entirely unproductive over all depths greater than 1,000 fathoms (most of which were in the Gulf Stream).

TABLE I

MILES TROLLED, NUMBER OF DOLPHIN CAUGHT OR LOST, AND AVERAGE MILES PER FISH HOOKED IN VARIOUS DEPTH ZONES

Depth zone (fathoms)	Miles trolled	Number of dolphin hooked and caught	Number of dolphin hooked and lost	Total number hooked	Average miles per fish hooked
0– 20	485	3	4	7	69
21– 50	270	11	14	25	11
51– 100	96	3	6	9	11
101–1,000	269	2	2	4	67
1,001–up	62	0	0	0	∞
Total, all zones	1,182	19	26	45	26

LENGTH AND WEIGHT.—The fork length in centimeters, weight in pounds, and sex of 18 of the fish (data not available for one) are plotted in Fig 1. The curve shown is of the type $y = ax^b$, and was fitted by means of least squares (Snedecor, 1940), using a logarithmic transformation. The equation is: $y = 0.0000144\, x^{3.231}$, where y = weight in pounds, and x = length in centimeters. The average length of all the dolphin was 82.7 centimeters (32.6 inches), and the average weight was 11.4 pounds. Males averaged a little larger than females (85.7 cm. and 13.0 lb. versus 81.2 cm. and 10.6 lb.) but no difference in the weights of males and females of a given length could be observed in these limited data.

The average weight was estimated for various lengths (over the range from 40 to 120 centimeters) although it meant extrapolating somewhat beyond the limits of our observed data. These estimated weights, shown in Table II, cover sizes of the majority of dolphin caught. The world record for rod and reel is recognized as 67½ pounds, the fish taken by Fred McNamara off Oahu, Hawaii, August 19, 1940, (LaMonte, 1946), but relatively few are taken over 30 pounds.

FOOD.—Flying fish (*Cypselurus heterurus*), several partially digested tuna-like fish believed to be *Euthynnus alletteratus*, and remains of some species of crab were found in several stomachs, but most were empty.

AGE, MATURITY, AND FECUNDITY.—Scale samples of 18 fish were impressed on cellulose acetate and examined under a microprojector. Marks thought to be annuli were found on some scales, but they were so indefinite that no reliable estimate of the age of these fish could be obtained. All fish that were observed (twelve females, six males) were sexually mature. Eggs were found in all females and these eggs appeared to be almost ripe. No spent fish were taken.

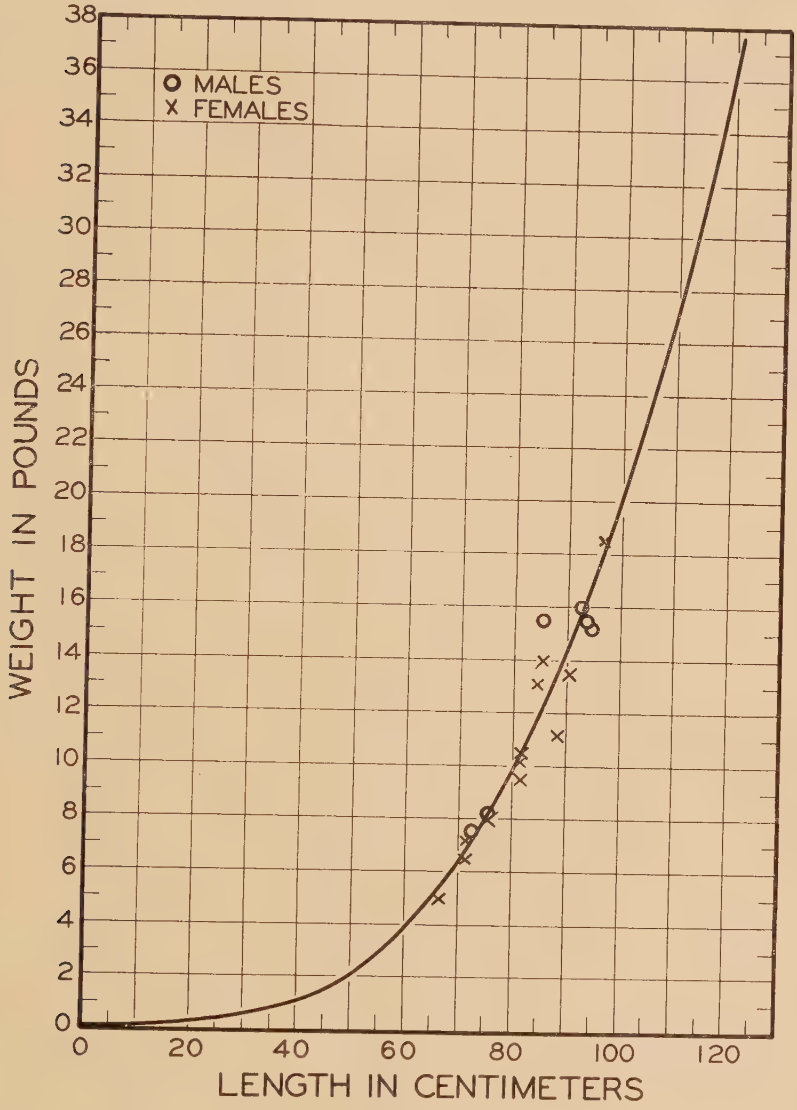

Fig. 1. Lengths and weights of 18 dolphin and calculated line expressing the length-weight relationship. Circles for males, crosses for females.

Gonads were preserved from six of the twelve females taken. The number of eggs in each gonad was estimated by counting a number of samples—each containing one cubic centimeter—and applying the average number per sample to the total content. The total number of eggs, per fish and per pound of fish, is shown in Table III. The average for all six females was 2,655,500 eggs per fish or 252,000 eggs per pound of fish.

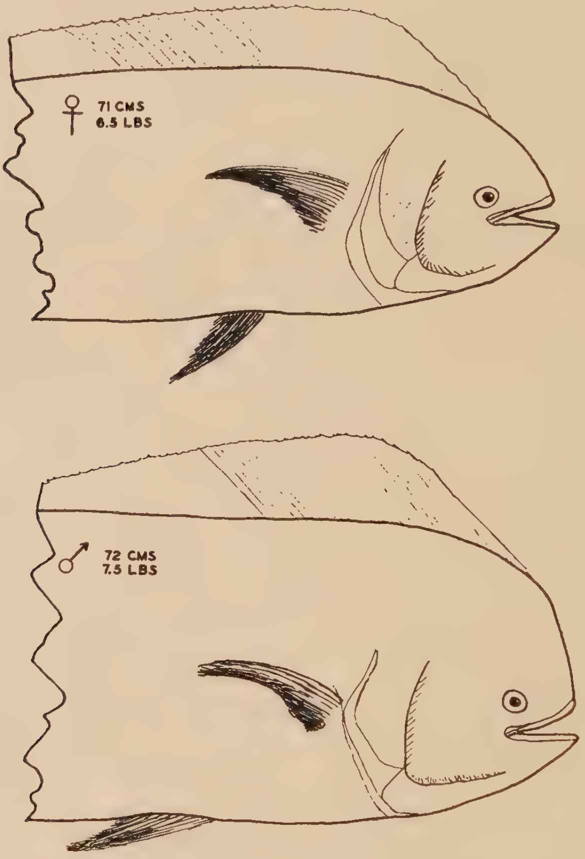

Fig. 2. The difference in form of heads of female and male dolphin.

Table II

Estimated Weights of Dolphin of Various Lengths

Length in centimeters	Weight in pounds	Length in centimeters	Weight in pounds
40	1.0	85	11.9
45	1.5	90	14.3
50	2.1	95	17.1
55	2.9	100	20.1
60	3.9	105	23.6
65	5.0	110	27.3
70	6.4	115	31.7
75	7.9	120	36.6
80	9.8		

TABLE III

ESTIMATED NUMBER OF EGGS CONTAINED IN THE OVARIES OF DOLPHIN

Weight of fish in pounds	Number of eggs	Number of eggs per pound of fish
6.5	1,706,000	262,462
8.0	1,672,000	209,000
9.5	2,641,000	278,000
10.2	1,937,000	189,902
10.5	1,887,000	179,714
18.5	6,090,000	329,189

SEXUAL DIMORPHISM.—There is a decided difference in form between adult males and females. This difference is evident largely in the shape of the head (Jordan and Evermann, 1896). Outlines were traced of the heads of two of the dolphin: a 72.5-centimeter, 7.5-pound male; and a 71.5-centimeter, 6.5-pound female; and these are shown in Figure 2.

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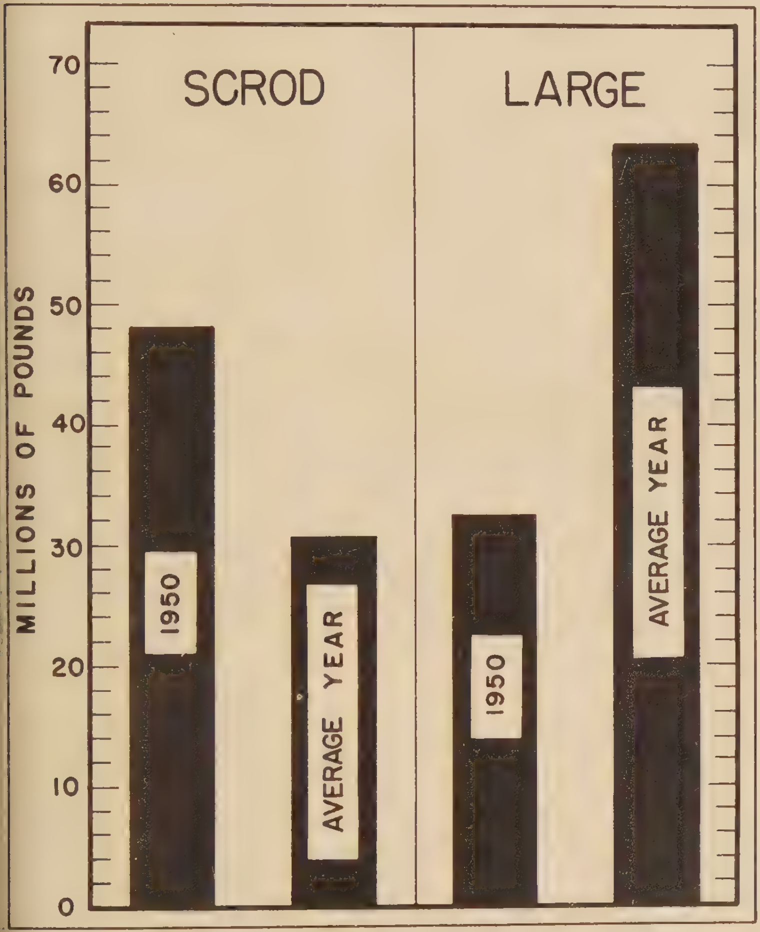
U. S. FISH AND WILDLIFE SERVICE, WOODS HOLE, MASSACHUSETTS.

U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
SEP. NO. 285

1950--AN UNUSUAL HADDOCK YEAR ON GEORGES BANK

By Howard A. Schuck* and John R. Clark*

The haddock catch from Georges Bank in 1950 was one of the most unusual in the istory of that Bank's fishery. This was due to very heavy landings of scrod, articularly during the summer, when some of the most exceptional trips on record were landed at the Boston Fish Pier. For instance, on July 11 one vessel hailed 100,000 pounds of scrod haddock and only 11,000 pounds of large haddock;[1] on August 15 another hailed 114,000 pounds of scrod and only 4,000 pounds of large; on August 21 a third hailed 115,000 pounds of scrod and 5,000 pounds of large. Twenty-four of these unusual trips hailed a total of 2,073,000 pounds of scrod and only 106,000 pounds of large--a ratio of 20 pounds of scrod to 1 of large.



IGURE 1 - THE POUNDS OF SCROD AND LARGE HADDOCK LANDED IN 1950 AS COMPARED WITH THE AVERAGE YEAR.

As a result of a continuing study of the haddock fishery by the U. S. Fish and Wildlife Service, certain facts concerning the 1950 catch are available.

This is the first year on record, for instance, that poundages of scrod landed have surpassed poundages of large haddock. The 1950 had-ock-year[2] catch from Georges Bank was composed of about 48,100,000 pounds[3] of rod and only 32,400,000 pounds of large, a ratio of 3:2, whereas in the average ar[4] the landings have been about 31,000,000 pounds of scrod and 63,000,000 unds of large, or a ratio of 1:2.

FISHERY RESEARCH BIOLOGISTS, NORTH ATLANTIC FISHERY INVESTIGATIONS, BRANCH OF FISHERY BIOLOGY, U. S. FISH AND WILDLIFE SERVICE, WOODS HOLE, MASSACHUSETTS.

AS DEFINED BY THE NEW ENGLAND FISH EXCHANGE, SCROD ARE HADDOCK OF 1-1/2 TO 2-1/2 POUNDS, LARGE HADDOCK ARE OVER 2-1/2 POUNDS.

THE HADDOCK YEAR, I.E., FEBRUARY THROUGH JANUARY, IS DIFFERENT FROM A CALENDAR YEAR BY ONE MONTH. QUANTITIES FOR THE LAST THREE MONTHS OF THE HADDOCK YEAR 1950 WERE PARTIALLY ESTIMATED.

DRAWN WEIGHT.

ALL AVERAGE DATA ARE FOR THE PERIOD 1931-48.

The numbers of fish landed show the great abundance of scrod more clearly than do the pounds landed. Of a total of 43,500,000 individual fish landed from Georges Bank in 1950, 34,300,000 were scrod and only 9,200,000 were large, or almost twice the number of scrod (18,200,000) and half the number of large (18,700,000) as are landed in the average year.

The sizes of haddock landed in 1950 differed considerably from the sizes landed in the average year. Figure 2 shows how the sizes in 1950 deviated from the average. The horizontal line at zero on the scale represents the norm. The numbers of each size of fish that exceeded the number for the average year are plotted above the zero line (+) and the number of each size that was less than the number for the average year are plotted below the zero line (-). For example, in 1950 there were about 1 million more fish of 13 inches than in the average year; about 6½ million more fish of 14½ inches; but some 2 million less fish of 19 inches than average. In brief, there were many millions more fish under 17 inches and many millions less fish over 17 inches than have been landed in the average year.

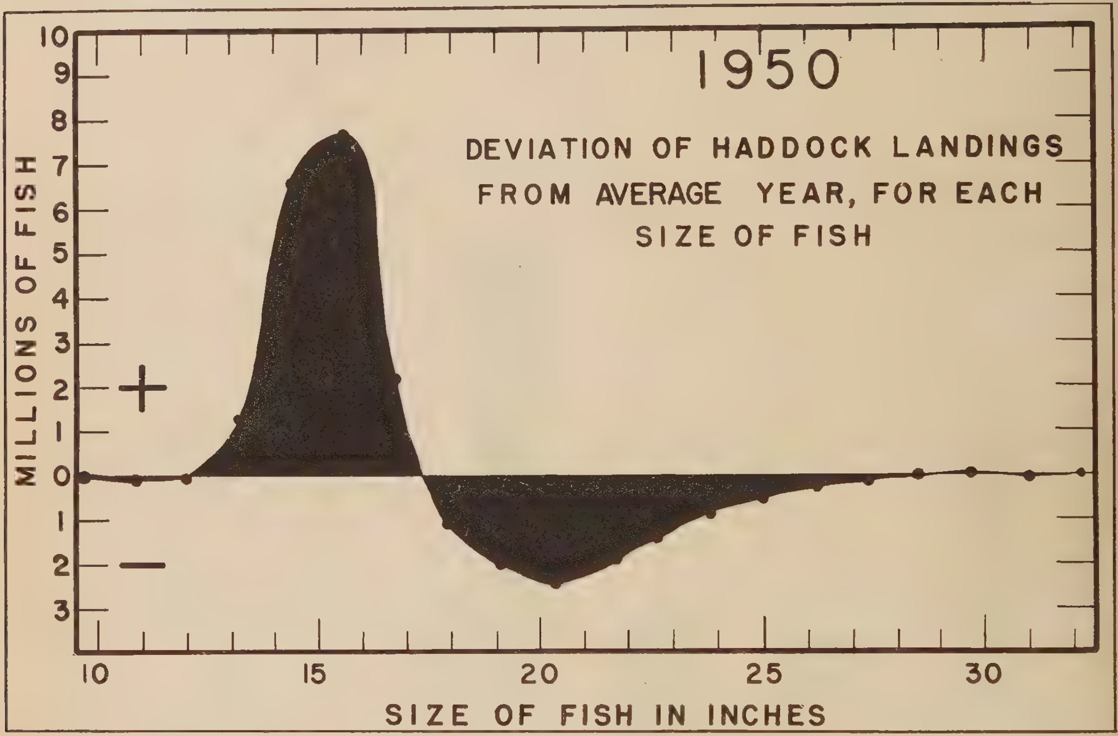


FIGURE 2 - DEVIATION OF 1950 HADDOCK LANDINGS FROM THE AVERAGE YEAR, FOR EACH SIZE OF FISH.

Most fish under 17 inches are smaller than the established lower limit for scrod.[5] More than 20,000,000 of these "undersized" haddock were landed from Georges Bank in 1950. In other words, almost half the total numbers caught were "undersized." In the average year less than 5,000,000 undersized haddock have been landed, and never before have more than 10,300,000 fish been landed.

The heavy catches of scrod lowered the individual average weight of all haddock landed in 1950 to only 1.85 pounds. The average weight has never before been below 2.27 pounds, and the average weight for the whole 18-year period has been 2.55 pounds.

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[5] SCROD, AS DEFINED BY THE NEW ENGLAND FISH EXCHANGE, INCLUDES HADDOCK OF 1-1/2 - 2-1/2 POUNDS (GUTTED WEIGHT). A 17-INCH HADDOCK AVERAGES SLIGHTLY OVER 1-1/2 POUNDS.

We have been able to assess the ages of haddock landed by examination of the scales collected at the Boston Fish Pier (Figure 3). Of all scrod landed from Georges Bank in 1950, 85 percent were 2-year-olds. In the average year only 47 percent of the scrod landed are of that age. It is apparent that the 1948 spawning (which produced these 2-year-olds) was one of the most successful, if not the most successful, in the history of the fishery. This year-class in its first two years has already contributed 29,700,000 fish to the landings, almost three times the number of fish contributed in a similar period by the average year-class.

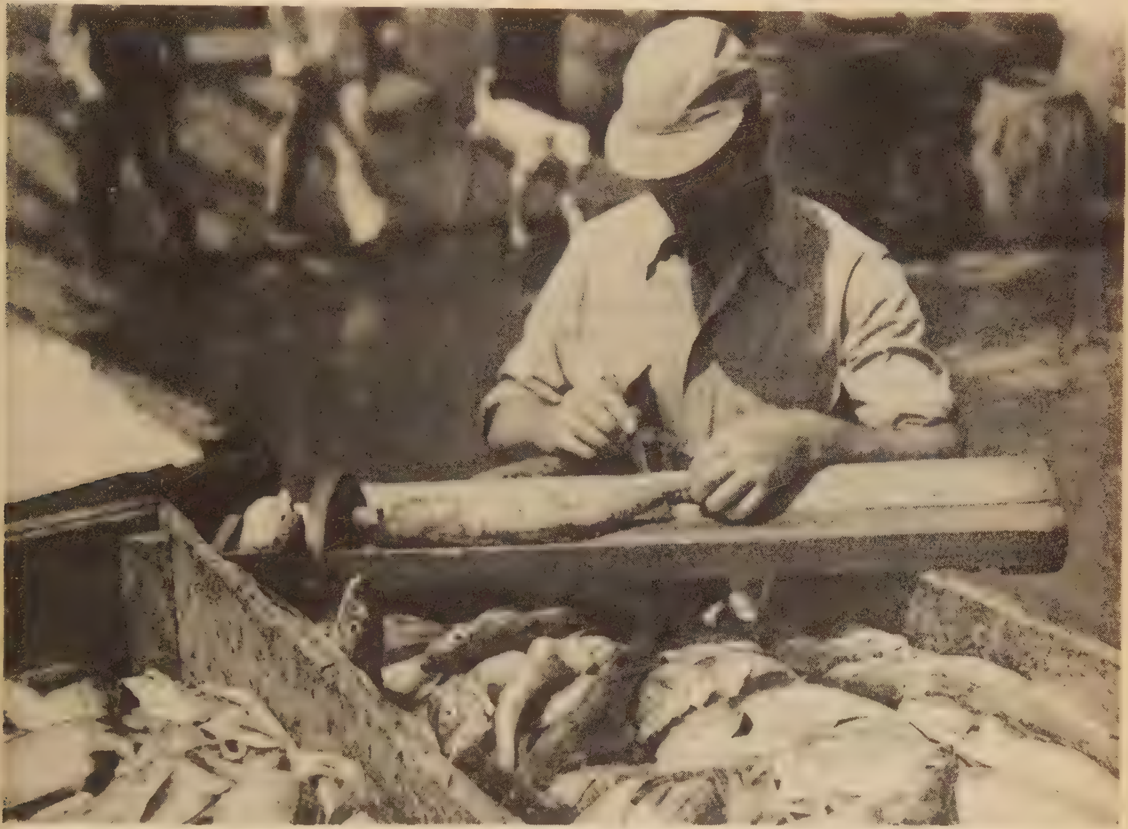

FIGURE 3 - OBTAINING SCALES FROM HADDOCK AT THE BOSTON FISH PIER FOR AGE DETERMINATION.

Of all other year-classes to enter the fishery since 1931, three were really outstanding. The large 1936 brood was primarily responsible for increased catches of haddock in the late 1930's, and the successful 1939 and 1940 broods provided good catches of haddock in the early 1940's. These three year-classes (1936, 1939, and 1940) all made greater-than-average contributions to the landings as 2-year-olds, yielding, respectively, about 200, 210, and 130 percent more two's than the average.

Although large catches have already been taken from the 1948-year class, it should continue to make large contributions to the fishery in the next few years. The effect, however, will now become less pronounced on catches of scrod. Thus, we can predict that the catches of large haddock will be somewhat greater in the next two or three years. Future catches of scrod, of course, will depend on the success of subsequent spawnings.

Reprinted from Copeia, 1951, No. 2, June 8

RECORD OF A WHITE-TIPPED SHARK, *CARCHARHINUS LONGIMANUS*, FROM THE NORTHWESTERN ATLANTIC.—A white-tipped shark, *Carcharhinus longimanus*, was caught from the U. S. Fish and Wildlife Service research vessel "Albatross III" on June 12, 1950, in the Gulf Stream at latitude 40°40.5′ N., longitude 57°01.5′ W., which is approximately east of New Jersey and south of Newfoundland. This specimen is noteworthy because of its place of capture, its stomach contents, and because it exhibits one previously uncertain morphological character.

Bigelow and Schroeder (1948, Fishes of the Western North Atlantic, Part 1 Sharks: 360–61) have shown that the species is evidently rare in the western Atlantic. Although they predicted it might occur off southern New England, the nearest record cited was for off Florida north of the Bahama Bank (seaward of the Gulf Stream). Our specimen was taken 700 miles farther north than this area. The identification was verified by Mr. Schroeder after the frozen specimen had been brought ashore.

The stomach of this shark contained a partly digested dolphin, *Coryphaena hippurus*, that had been bitten in half; no other recognizable food was found. Dolphin are exceedingly fast swimmers and have not been recorded previously as part of the diet of any of the Carcharhinidae, at least not in the memory of Mr. Schroeder. There is no evidence that the dolphin was captured while actively swimming. Its size (estimated at about 36 inches and about 14 pounds) is well below the maximum attained by this species, and thus old age might be ruled out. The dolphin might have been injured, diseased, or in some stage of sleep (if dolphin do sleep); or, on the other hand, it might have been in good health and actively swimming.

We trolled surface lines on this cruise and captured and saw a number of dolphin. It is interesting, however, that none was observed near where the shark was captured, nor anywhere east of longitude 63°W., although a considerable amount of trolling and watching for them was done in this area of the Gulf Stream.

Bigelow and Schroeder (*op. cit.*: 357) stated that embryos of *Carcharhinus longimanus* have ". . . a low dermal ridge occupying the middle 2/3 of the space between 1st and 2nd dorsals . . ." They were not sure that adults had this ridge as they wrote "We did not appreciate the importance of this character at the time when we examined the adults . . ." The adult specimen here recorded does have a distinct dermal ridge along the midline of the back but it occupies only about 1/3 of the space between the 1st and 2nd dorsals. This shark is a female, 199 cm. in overall length, and contained no young.—Howard A. Schuck and John R. Clark, *U. S. Fish and Wildlife Service, Woods Hole, Massachusetts.*

Reprinted from COPEIA, 1951, No. 3, August 31

A BLACKFIN TUNA (*PARATHUNNUS ATLANTICUS*) FROM NORTH CAROLINA WATERS.—During a cruise of the U. S. Fish and Wildlife Service research vessel ALBATROSS III off the coast of North Carolina in June, 1949,[1] a single specimen of blackfin tuna, *Parathunnus atlanticus* (Lesson), was collected. It was taken on a surface-trolled lure about 20 miles south-southeast of Cape Hatteras (34°56′ N., 75°22′ W.) in water of 50 fathoms. The fishing methods used on this cruise are recorded in a paper by Schuck (1951, COPEIA (1): 35–39) which described the dolphin taken at this time.

From criteria given in Beebe and Tee-Van (1936, Zoologica, 21: 180–84)—largely the gill-raker counts—we have identified the specimen as the blackfin tuna, rather than the yellowfin tuna, *Neothunnus argentivittatus* (Cuvier), to which it bears a close external resemblance. Beebe and Tee-Van gave the range of gill-raker counts for *P. atlanticus* as 5 to 6 + 15 to 18 for 52 Bermuda specimens and 5 to 6 + 15 to 16 for 25 British West Indies specimens. Their counts for *N. argentivittatus* were 10 and 11 + 21 for 1 Bermuda fish and 9 or 10 + 20 to 22 for 3 British West Indies specimens. Our specimen has 6 + 17 gill rakers on the left arch and 5 + 17 on the right; these counts are clearly in the range of variation for *Parathunnus atlanticus*. Other measurements and counts for this specimen (made after preservation for six months in formalin), following the method of Marr and Schaefer (1949, U. S. Fish and Wildlife Ser., Fishery Bull., 47: 241–44), are as follows: Total length, 42.5 cm.; head length, 12.0 cm.; snout to insertion of first dorsal, 13.4 cm.; snout to insertion of second dorsal, 24.0 cm.; snout to insertion of anal, 26.8 cm.; snout to insertion of ventral, 13.9 cm.; greatest depth, 11.3 cm.; length of pectoral, 11.7 cm.; pectoral insertion to insertion of first dorsal, 6.4 cm.; length of base of first dorsal, 9.8 cm.; length of base of second dorsal, 4.1 cm.; spread of caudal, 12.2 cm.; length of longest dorsal spine, 5.0 cm.; length of first dorsal spine, 5.0 cm.; length of second dorsal, 3.5 cm.; length of anal, 2.9 cm.; length of longest dorsal finlet, 1.4 cm.; diameter of iris, 1.2 cm.; length of maxillary, 5.0 cm.; least depth of caudal peduncle, 1.0 cm.; greatest width of caudal peduncle at keels, 2.6 cm.; number of first dorsal spines, 13; number of dorsal finlets, 9; number of anal finlets, 8. Sex, female; weight, 3.75 lbs.

The range of *Parathunnus atlanticus,* according to Beebe and Tee-Van (1936), is "Known from the coast of Florida, Bermuda, Haiti, Martinique, the following islands in the British West Indies: St. Lucia, Union, Grenada and Tobago, and from Trinidad Island, Brazil." Whiteleather and Brown (1945, Anglo-American Caribbean Comm., Washington, D. C.: 107) listed this tuna in "An Experimental Fishery Survey in Trinidad, Tobago, and British Guiana," and Rivas (1949, Fla. Bd. Conserv., Ed. Ser. 4: 10) recorded it in "Check List of the Florida Game and Commercial Marine Fishes." We can find no reference to its occurrence north of Bermuda, or north of Florida along the United States coast. The capture of the fish off North Carolina, therefore, constitutes an unusual record, if not a new northern record for the species.—HOWARD A. SCHUCK, *U. S. Fish and Wildlife Service, and* FRANK J. MATHER, III, *Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.*

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[1] This cruise was undertaken jointly by the Institute of Fisheries Research of the University of North Carolina and the U. S. Fish and Wildlife Service. This report appears by permission of both organizations.

U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
SEP. NO. 284

June 1951 **Washington 25, D.C.** **Vol.13,No.6**

JAPANESE TUNA-MOTHERSHIP OPERATIONS IN THE WESTERN EQUATORIAL PACIFIC OCEAN

By Bell M. Shimada*

INTRODUCTION

Motherships were used by the Japanese with notable success to exploit the rich almon and crab resources of the north Pacific Ocean in prewar days; however, these obile processing units were not similarly associated with the tuna fisheries. Peraps the most important of several considerations which precluded the introduction f the mothership system during the 1930's, when the expansion of the offshore fishry for tuna was at its greatest, were:

1. JAPANESE FISHING COMPANIES WERE ALREADY REAPING LARGE PROFITS FROM THE NORTHERN PACIFIC FISHERIES
2. BECAUSE THE POTENTIALLY RICH EQUATORIAL TUNA FISHERY WAS COMPARATIVELY UNDEVELOPED AT THAT TIME.

onsequently, they were not interested in transferring their large vessels to a then omparatively undeveloped equatorial Pacific Ocean tuna fishery.

Growth of the winter fishery for albacore in the mid-Pacific during this perod focused some interest on motherships as a means of effectively harvesting this istant resource. However, no concrete efforts were made in this direction because t was thought that climatic conditions would present operational problems of inurmountable difficulty. Furthermore, the exigencies of war on the Asiatic mainland ere already starting to have their effects on the Japanese fishing industry, and he larger vessels were being commandeered by the Navy. What plans, if any, the inustry may have had for employing motherships in tuna fishing were completely disupted by the outbreak of war with the United States in 1941.

Despite the lukewarm attitude of the Japanese fishing industry to proposals of sing motherships in the tuna fishery, technical research of such operations was by o means lacking. In 1931, the Japanese Government sent a mothership to Indo-Ausralian waters for the dual purpose of investigating the possibilities of using a rocessing ship with its own auxiliary fishing vessels to exploit distant tuna reources and to discover new fishing grounds. The expedition was repeated in 1932 nd 1933, and the results were published in Japanese government reports. As far as s known, however, no follow-up action was taken by the fishing industry even though hese explorations revealed the presence of yellowfin tuna populations of sufficient agnitude to support a commercial fishery in the Celebes and Sulu Seas.

In 1948 and 1949, small mothership operations were attempted by the Japanese n waters around the Bonin Islands, and eastward to albacore grounds. These attempts ere commercially unsuccessful because of poor fishing results and operational difculties.

Elsewhere in the Pacific Ocean, the only other tuna-mothership operations were nducted experimentally by the United States with the Reconstruction Finance Corporion's *Pacific Explorer*, an American-built factory vessel. The *Pacific Explorer*,

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equipped to dry-freeze and store tuna, operated from January to July 1947 in wate off Central and South America (Carlson 1948).

A new phase of the Japanese tuna fisheries was launched on May 11, 1950, approximately 4½ years after the close of World War II. The Commander-in-Chief Pacific and U. S. Pacific Fleet and High Commissioner of Trust Territory of the Pacific Islands, and the Supreme Commander for the Allied Powers (SCAP) gave permission to the Japanese (SCAP directive No. 2097,[1] May 11, 1950) to send tuna-mothe ship expeditions to defined areas of the high seas adjacent to the Caroline, Marianas, and Marshall Islands.

This permission was granted subject to the following terms and conditions:

1. THAT RECORDS OF FISHING AND FISH CATCHES BE KEPT BY THE JAPANESE OPERATOR, AS SPECIFIED BY THE HIGH COMMISSIONER, TRUST TERRITORY OF THE PACIFIC ISLANDS.

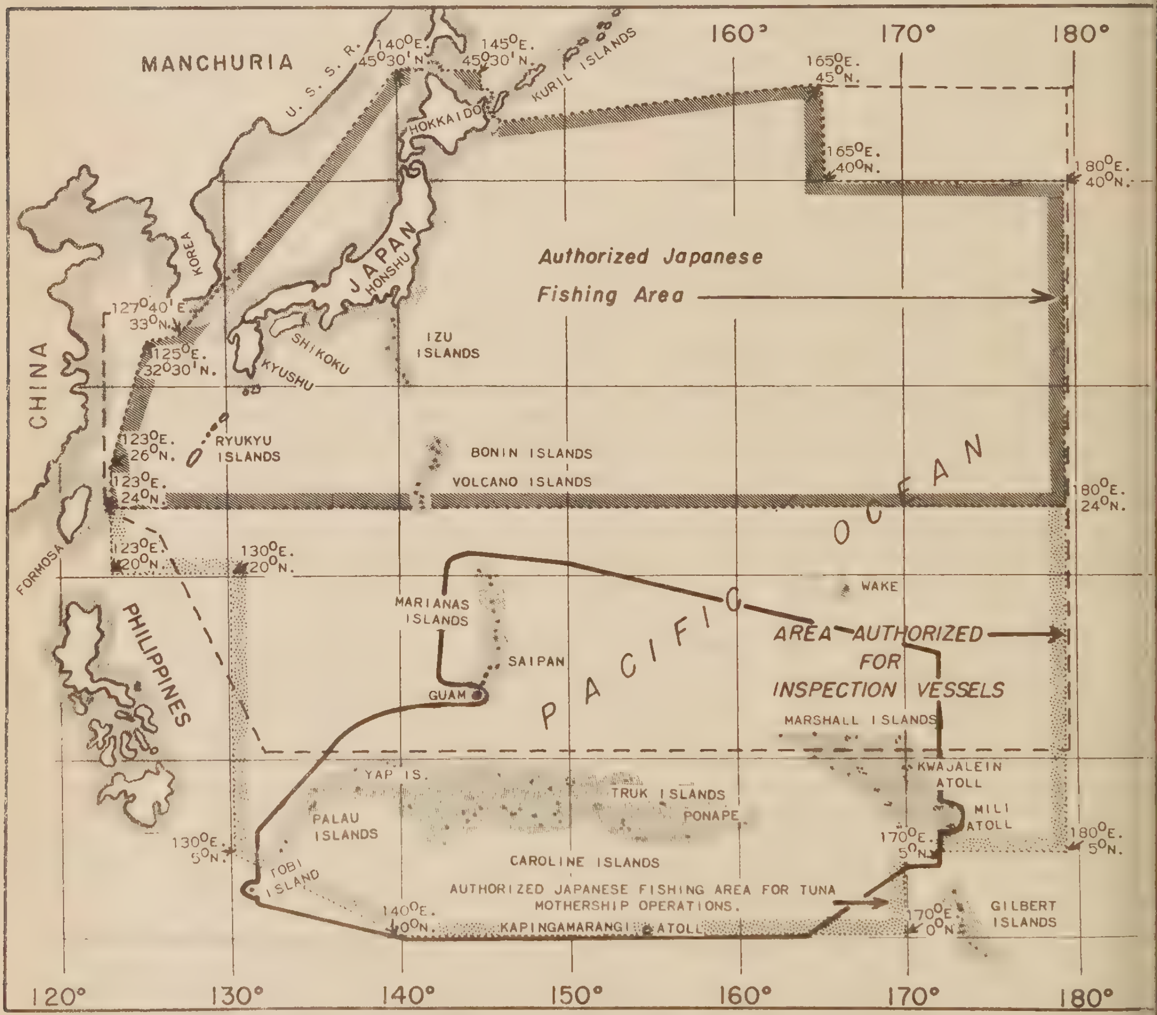

FIGURE 1 - HORIZONTALLY-LINED BORDER INDICATES EXTENT OF THE CINCPAC-SCAP AUTHORIZED JAPANE FISHING AREA AS OF MAY 11, 1950. BROKEN BLACK LINE INDICATES AREA AUTHORIZED FOR JAPANES INSPECTION VESSELS. DOTTED-STIPPLED BORDER SHOWS EXTENSION SOUTH OF 24° N. LATITUDE TO T EQUATOR FOR JAPANESE TUNA MOTHER-SHIP OPERATIONS. SOLID BLACK LINE AROUND MARIANAS, MARS AND CAROLINE ISLANDS SHOWS THE U. S. TRUST TERRITORY OF THE PACIFIC ISLANDS.

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[1] COMMERCIAL FISHERIES REVIEW, JUNE 1950, PP. 52-4.

2. THAT PROVISION BE MADE FOR A REPRESENTATIVE OF THE HIGH COMMISSIONER AND THE U. S. FISH AND WILDLIFE SERVICE TO BOARD OR ACCOMPANY VESSELS OF ANY EXPEDITION FOR PURPOSES OF OBSERVATION AND INSPECTION, AND THAT A REPRESENTATIVE OF SCAP ACCOMPANY EACH FLEET.
3. THAT PROVISION BE MADE FOR VESSELS OF THE FLEET TO REPORT THEIR POSITIONS DAILY BY RADIO.
4. THAT NO VESSEL OF THE EXPEDITION APPROACH CLOSER THAN THREE MILES TO ANY LAND NOT UNDER THE ADMINISTRATIVE CONTROL OF THE JAPANESE GOVERNMENT.
5. THAT SUPERVISION OF ALL OPERATIONS WAS BY RESPONSIBLE JAPANESE OFFICERS WHO WOULD INSURE UNDER ALLIED SUPERVISION RIGOROUS COMPLIANCE WITH ALL STIPULATIONS OF THE DIRECTIVE.

Immediately following the issuance of this directive, the work of organizing and conducting the first large-scale, commercial tuna-mothership expedition in Japanese fisheries history was undertaken by the Taiyo Fishing Company, Ltd., one of Japan's largest and most aggressive fishery concerns. The fleet consisted of a large refrigerated carrier ship detached from the company's Antarctic whaling fleet, 13 company tuna-fishing vessels, and 12 independently-owned vessels. It was assembled and outfitted for three months' operations in the newly-approved area (Figure 1). That a part of the mothership fleet was able to leave Tokyo on June 8, 1950, less than a month after formal approval, reflects not only the readiness of the Japanese to take advantage of their opportunity to fish the South Seas again, but also the haste with which preparations were made.

The following report deals with various aspects of Japanese tuna fishing and mothership operations observed while the author was with the expedition from June 12, 1950, to September 14, 1950, as a scientific and technical observer for the High Commissioner for the Trust Territory of the Pacific Islands and the U. S. Fish and Wildlife Service. Information and data regarding mothership practices and equipment were obtained largely through interviews with vessel personnel and through personal observation. Methods of fishing long-line gear were witnessed at sea aboard a fishing vessel attached to the fleet.

Statistics included in this report, together with other source material, were made available by the High Commissioner of the Trust Territories, the Supreme Commander for the Allied powers, and the Japanese Government.

OPERATING AREA AND SEASON

The mothership arrived on the fishing grounds on June 17, 1950. Fishing by 5 of her catchers commenced on that date in the vicinity of 4° 35' N. latitude and 143° 32' E. longitude (Figure 2). The remaining fishing vessels joined the fleet shortly thereafter, and the last catcher began her operations on July 14. As the season progressed, the expedition as a unit gradually moved eastward at a weekly rate of about 100 miles. The catchers confined their latitudinal activities between 1° and 9° N. latitude. Shifts in position of the mothership and fishing vessels and rate of longitudinal movement were determined largely by the success of fishing encountered in any one area. Fishing was conducted mostly between 1° and 5° N. latitude because of previous knowledge that the best catches of tuna could be made in this zone. When processing operations aboard the mothership were halted on September 2, the vessel's position was 5° 04' N. latitude and 157° 01' E. longitude. All fishing ceased on September 5, 1950, and the expedition headed back to Japan.

OPERATING RESTRICTIONS

Although the Japanese were authorized by SCAP to fish as far south as the Equator, for purposes of control the Japanese Government, through its representatives,

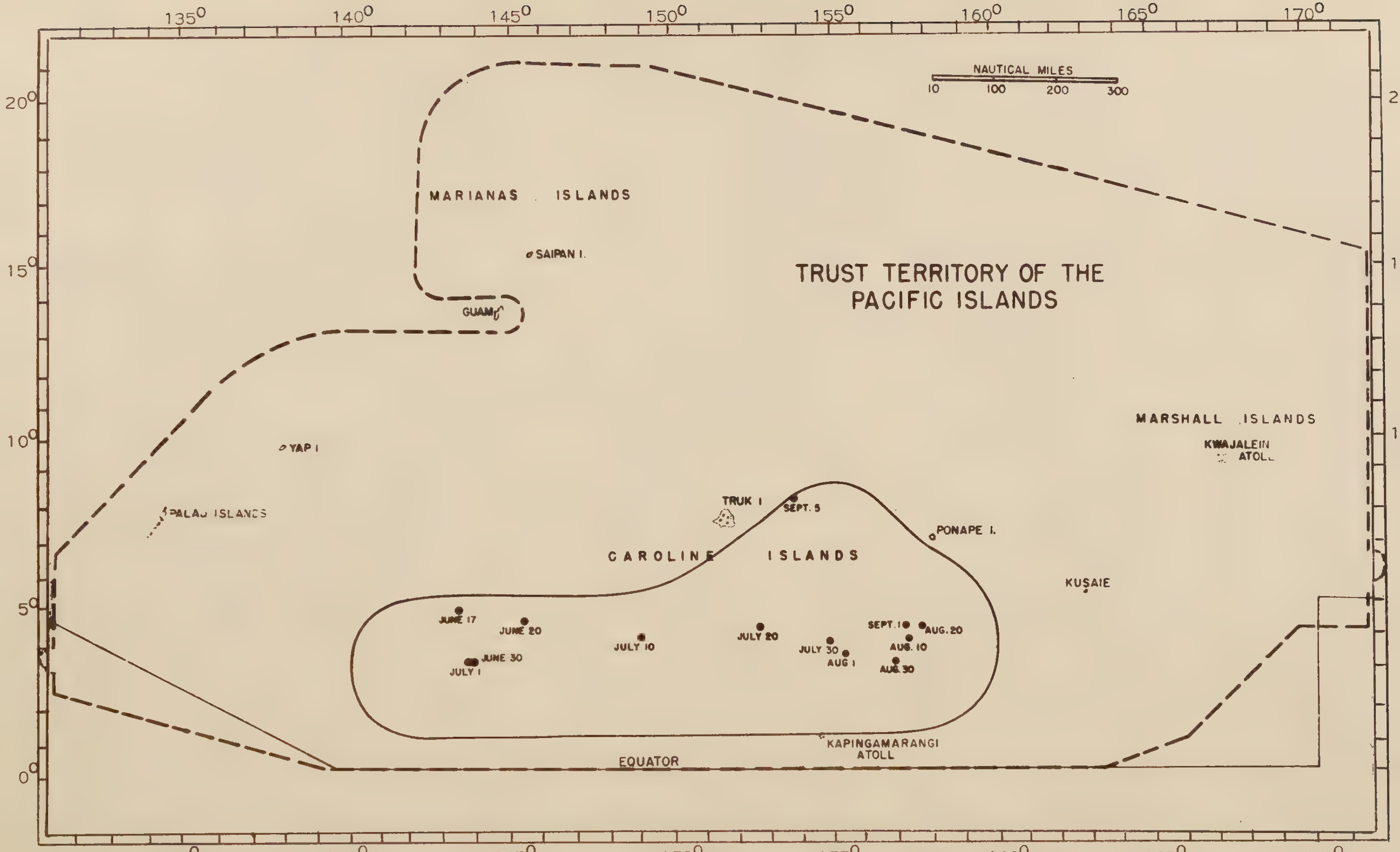


FIGURE 2 - GENERAL AREA OF OPERATIONS (SOLID BLACK LINE) IN WATERS SURROUNDING TRUST TERRITORY OF THE PACIFIC ISLANDS (DOTTED LINE) OF THE FIRST JAPANESE TUNA-MOTHERSHIP EXPEDITION. DATED POSITIONS ARE THOSE OF THE MOTHERSHIP DURING THE SEASON, FROM JUNE 17 TO SEPTEMBER 5, 1950.

imited the southward movements of the mothership to 3° N. latitude, and the maximum istance that any catcher boat could operate from the mothership was set at 200 miles. atchers desiring to fish beyond the 200-mile limit were allowed to make application or permission to do so. Furthermore, no fishing was permitted south of 1° N. latitude or within 10 miles of any islands.

FISHING OPERATIONS

Fishing Vessels: The fishing potential of the expedition was vested in the 25 ong-line fishing vessels from various Japanese ports. These vessels ranged in size rom four small 60-80 gross-metric-ton wooden vessels to modern steel-built ships of 150-200 gross tons, which comprised the rest of the fleet. Over-all length of the atter ranged from about 70 to 110 feet.

The typical Japanese long-line vessel resembles an Atlantic well-deck trawler and is characterized by a strong shear line (Figure 3). Power is usually supplied y a Diesel engine and, in many cases, auxiliary gaff-rigged sails are also carried to supplement the main engine. The wheel house is located amidships and the engine room is aft. This setup provides ample working space forward, which is free of excess deck structures, except for the long-line hauler which may be situated on the ort or starboard side. Often, two long-line haulers are so installed that fishing ear may be taken in from either side. Removable doors are cut into the bulwark or bringing fish and gear aboard.

Holds for the catch are located beneath the well deck and are generally not quipped with refrigeration equipment. Ammonia coils, if present, are for the purpose of preventing the rapid melting of ice rather than for freezing fish.

Crew's quarters are located forward in the forecastle and aft of the engine oom. Because of the number of men carried by a long-line vessel (18 to 27 according to size of boat), these quarters are generally cramped. The galley is on the ain deck aft and has space only for the preparation of food; no room is provided or eating indoors.

Fishing Gear: The long line is a form of gear developed and used by the Japanese to fish deep levels of the ocean for large pelagic fish, such as tunas and spearfishes. A good description of the evolution of long-line gear, the construction of omponent parts, and methods of fishing is given by Shapiro (1950) in his report on he Japanese long-line fishery.

The basic unit of long-line fishing gear is the "basket".[2/] A basket consists f several sections of main or trunk line, usually cotton, to which are tied a number of branch lines and a float line (Figure 4). Each branch line is made up of a ngth of cotton line; or a "sekiyama" or "shanawa" (cotton thread wound around a ore of wire or fiber); a wire leader and hook. Lines, including the "sekiyama," e coated with tar to prevent deterioration and to add rigidity for ease of handling.

The branch lines, float line, and sections of the main line comprising a basket e tied together with knots so that the gear may be easily taken apart (Figure 4. sets 1, 2, 3, 4, 5, 6, 7). This is of advantage when it is necessary to replace a anch line or to remove a branch line or entire basket from the main set of gear. e knots that are used differ with the fishermen but are usually those which, while mple to tie and untie, are not bulky and will hold firmly. A swivel is sometimes aced at the end of the cotton section of a branch line before the "sekiyama" to ep the branch line from twisting and tangling.

[2/] THIS TERM ORIGINATED FROM THE FACT THAT FORMERLY SECTIONS OF LONG-LINE GEAR WERE KEPT IN BAMBOO BASKETS. THIS METHOD OF STOWING GEAR, ALTHOUGH STILL IN USE IN PARTS OF NORTHERN JAPAN, IS GRADUALLY BEING DISCARDED AND NOW A BASKET OF GEAR IS USUALLY TIED INTO A BUNDLE, USING A FOUR-PIECE SLING MADE OF OUTWORN COTTON LINE.

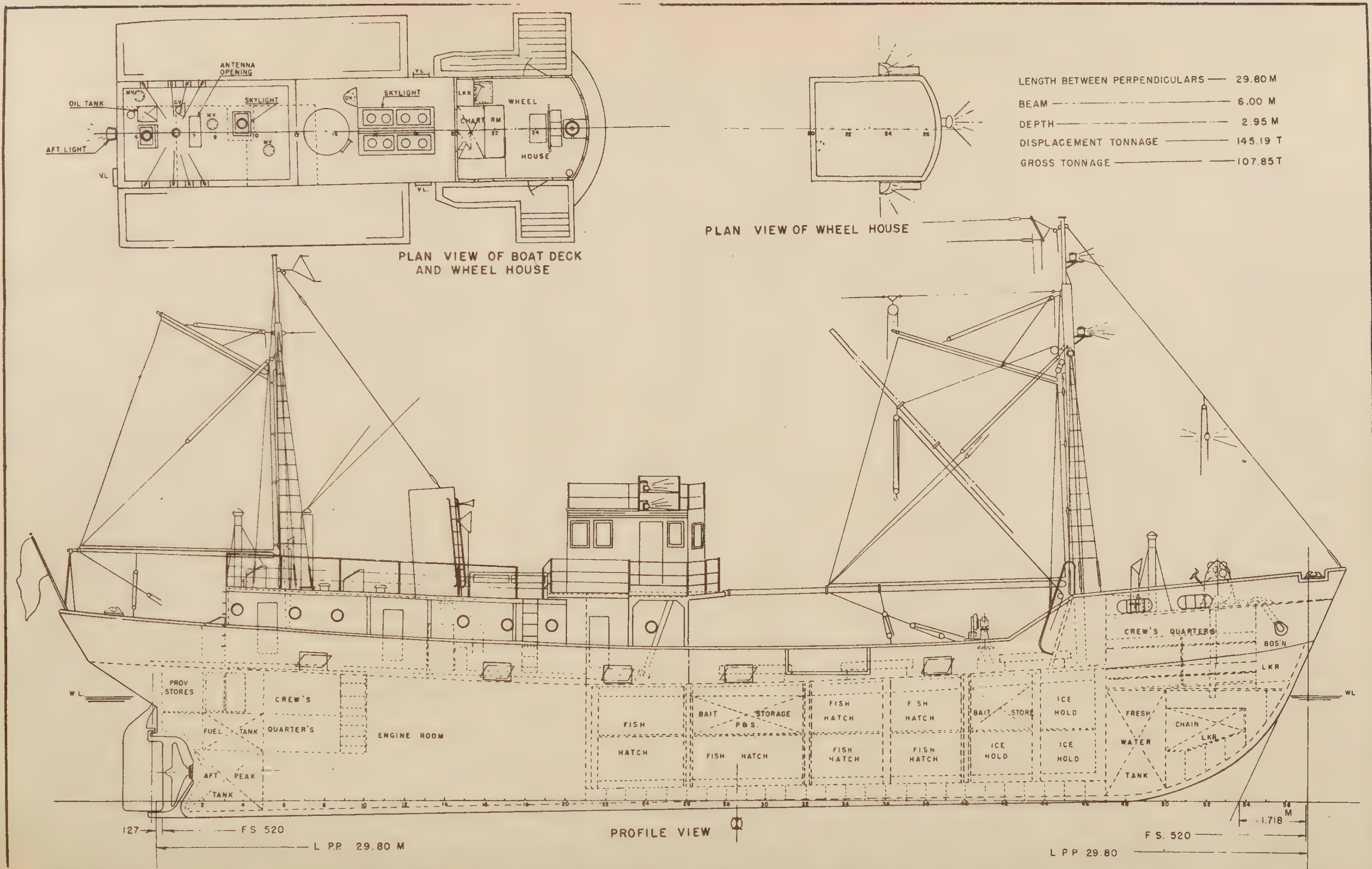
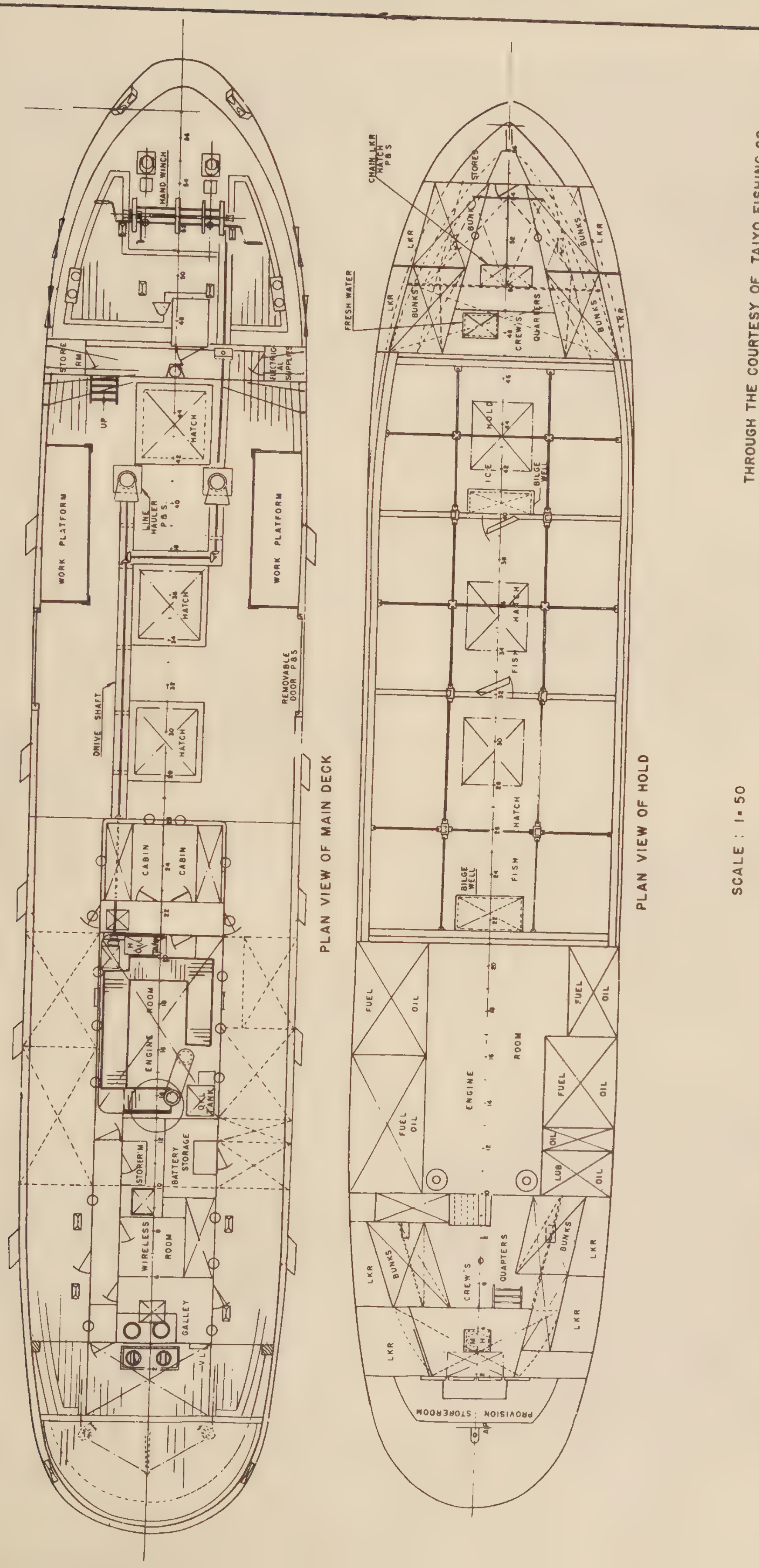


FIGURE 3 - GENERAL PLAN OF CONSTRUCTION OF A JAPANESE LONG-LINE FISHING VESSEL.
PART I - PROFILE OF VESSEL AND PLAN VIEW OF BOAT DECK AND WHEELHOUSE. MEASUREMENTS SHOWN IN METERS AND METRIC TONS.



THROUGH THE COURTESY OF TAIYO FISHING CO., TOKYO, JAPAN.

FIGURE 3 - GENERAL PLAN OF CONSTRUCTION OF A JAPANESE LONG-LINE FISHING VESSEL. PART II - PLAN VIEWS OF MAIN DECK AND HOLD. MEASUREMENTS SHOWN IN METERS AND METRIC TONS. (SEE PREVIOUS PAGE FOR PROFILE OF VESSEL AND PLAN VIEW OF BOAT DECK AND WHEELHOUSE.)

The baskets are tied in one continuous line when a set is made. Glass or met floats, varying in diameter from 10 to 12 inches, are used to buoy the main and branch lines at subsurface levels. These floats are tied to bamboo poles which, i turn, are tied to the float lines. A pole and float combination, therefore, marks the junction of each basket of gear. The bamboo poles, often referred to as "flag serve as markers to show the fisherman the location and in what direction his gear is set. Together with the floats, the flags also indicate by their movements at t surface whether fish have been caught on the branch lines (Figure 5). Struggling fish will usually cause the floats to bob and the flags to fall over to one side. Dead fish on the lines will by their weight draw two float-and-pole combinations together, and the floats in this case will either be submerged or awash while the flags will be vertical and with little wavering.

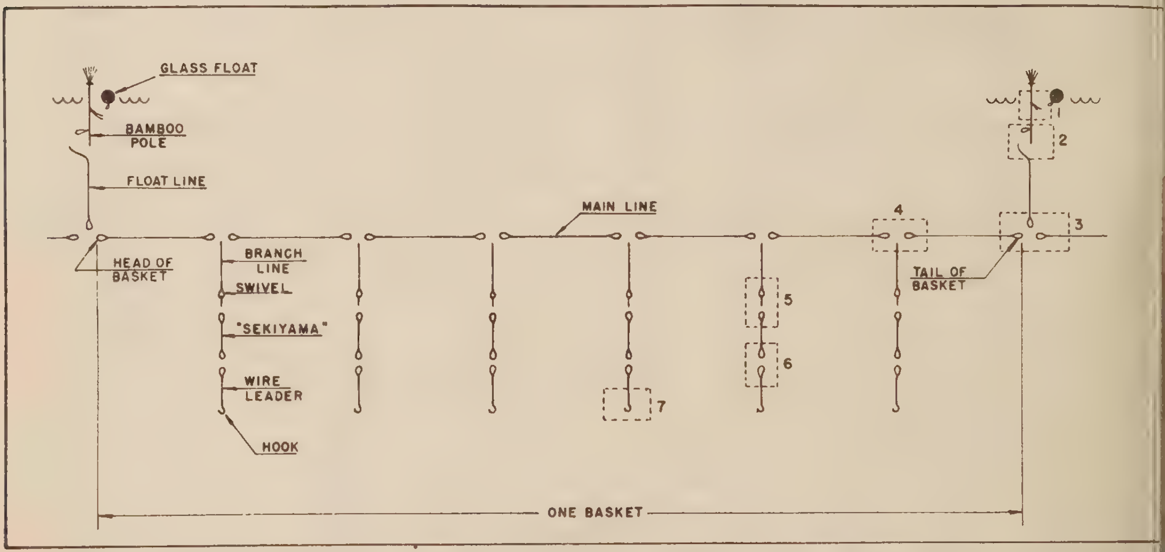


FIGURE 4 - DIAGRAM SHOWING THE COMPONENT PARTS OF A BASKET OF TUNA LONG-LINE FISHING GEAR. INSETS ILLUSTRATE KNOTS THAT ARE GENERALLY USED IN ASSEMBLING THE DIFFERENT SECTIONS. (SEE INSETS ON PAGE 9.)

Light buoys are used to mark the location of the gear at night and to guide the fishermen when retrieving gear during the hours of darkness. In comparativel calm waters, light buoys are usually placed at 20- to 25- basket intervals and on for the portion of the gear which is expected to brought in after dark. In areas where rough weat prevails, more buoys are used and they are space closer together.

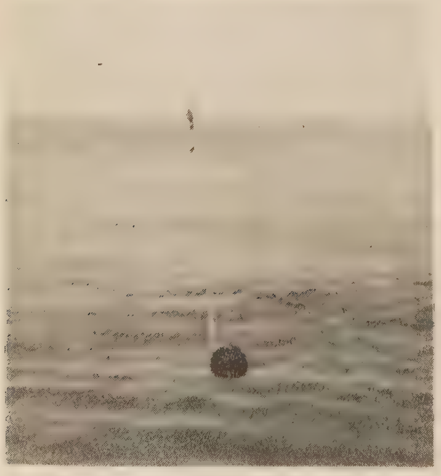
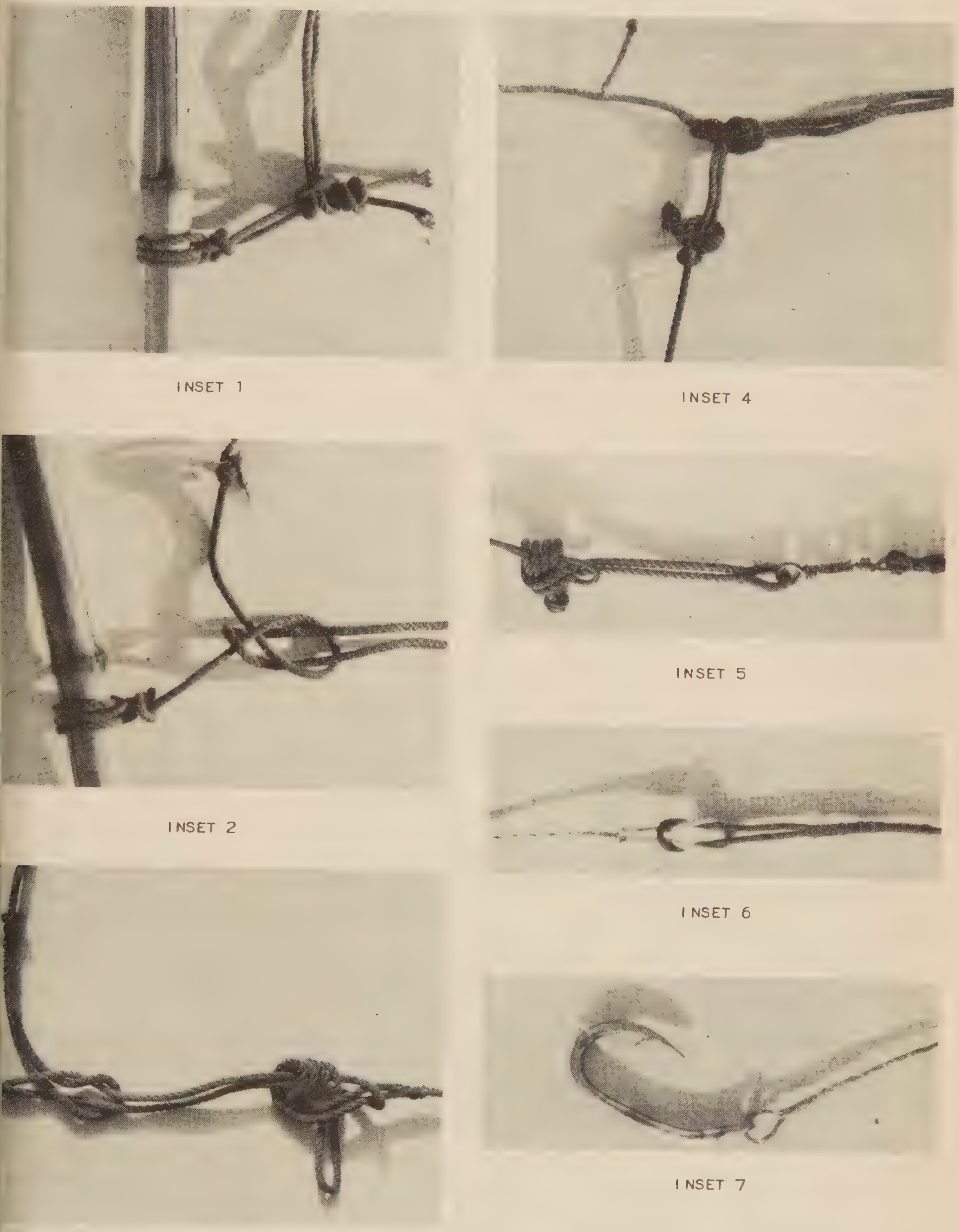


FIGURE 5 - A BAMBOO POLE AND GLASS FLOAT AT THE SURFACE. CALM SEAS AS SHOWN PREVAILED THROUGHOUT THE SEASON.

Because of the calm seas encountered in the latitudes of the western Pacific, the vessels of expedition were able to fish a maximum number of baskets. The number of baskets per vessel set da varied from 250 for the smaller vessels to 400 baskets for the larger catchers, the average number being 350 baskets or the equivalent of about 65 miles of main line. In the north central Pacific long-line fishery for albacore, where the vessels are normally engaged during the winter months, th are usually unable to fish more than 250 baskets per day because of weather conditions. Table 1 gives the amount and dimensions of gear used by t expedition's long-line vessels.



INSET 1

INSET 2

INSET 3

INSET 4

INSET 5

INSET 6

INSET 7

INSETS FOR FIGURE 4 WHICH APPEARS ON PAGE 8.

Methods of Locating Fishing Grounds: Japanese tuna fishermen have long been aware of the fact that the marginal areas of two different water masses in juxtaposition are productive of fish. In northern waters, these zones of discontinuity are usually characterized by a steep surface temperature gradient. According to the fishermen, however, such current contact areas are not as well defined in lowe latitudes because surface water temperatures do not vary as greatly for the differ ent current systems. For this reason, water temperatures were not relied upon to any extent by fishermen of the expedition as an aid to locating productive grounds associated with current borders.

Table 1 - Amount and Dimensions of Long-Line Gear Fished by Vessels of the Tuna-Mothership Expedition[1]

Name of Vessel	Gross Tonnage	Baskets	Total Length of Basket	Branch Lines	Length of Cotton Section of Branch Line	Length of "Sekiyama"	Length of Float Lin
	Metric Tons	Number	Feet	Number	Feet	Feet	Feet
Asahi No. 1	60	250	894	5	36	24	72
Asahi No. 7	84	250	894	5	42	24	95
Azuma No. 1	138	360	1253	6	36	24	78
Azuma No. 2	139	400	894	5	48	24	84
Azuma No. 3	147	350	1043	6	39	24	66
Azuma No. 5	146	380	894	5	39	24	66
Azuma No. 6	145	350	1043	6	36	24	72
Azuma No. 7	145	340	1043	6	36	24	60
Daikoku No. 12	136	370	894	5	48	24	72
Genei No. 1	149	350	917	7	36	30	78
Kaiko	147	352	894	5	36	24	66
Kotoshiro No. 1	157	400	894	5	36	22	48
Kuroshio No. 7	160	370	1074	5	36	24	89
Marutaka No. 11	146	320	1043	6	36	18	66
Nankai No. 2	76	250	894	5	36	24	75
Nankai No. 3	80	300	894	5	36	24	95
Reiyo	142	370	1043	6	36	30	42
Sasayama No. 7	158	350	894	5	24	24	72
Seiyo No. 2	144	360	1127	6	48	15	72
Shinko No. 30	150	350	1074	5	36	24	72
Shinko No. 80	206	360	1043	6	24	24	95
Shinyo No. 8	154	340	1074	5	36	24	72
Shiratori	158	404	1074	5	36	24	63
Sumiyoshi No. 6	196	380	1043	6	36	21	78
Sumiyoshi No. 21	158	333	1043	6	30	24	72

[1] LEADER LENGTHS, NOT INCLUDED, AVERAGED 6 FT.; ALL LENGTHS ARE TO THE NEAREST FOOT.

Current direction was used as a general guide, however, in determining the eddy areas of the equatorial countercurrent, which flows from west to east betwe 2° and 10° N. latitude in the western Pacific (Shapiro 1948). Its width and pos tion depend upon the season and area. The equatorial countercurrent is bordered on the north by the westerly flowing north equatorial current and on the south b the south equatorial current, which also travels in a westerly direction. Sinc the average seasonal position of the equatorial countercurrent has been fairly well determined for the western equatorial region by Japanese hydrographic surve the fishermen were able to estimate where the boundaries were in general by the of charts. The drift of vessels and gear then served as additional checks. (A general discussion of factors which govern the selection of fishing grounds in t equatorial countercurrent and hydrographic features associated with good fishing may be found in a report by Inanami, 1942.)

Long lines were generally set at an angle to the flow of the equatorial cou tercurrent to assure the gear a greater chance of fishing a part of the current contact zone and to prevent tangling of the lines. When certain sections of the gear yielded better catches than others, the lines were reset to fish such areas more heavily. Sets were seldom made in the vicinity of islands because of operating restrictions and the opinion that larger fish are not to be found near the islands. Furthermore, it was believed that sharks were more abundant in inshore waters than in areas removed from land.

Methods of Fishing Long-line Gear: The techniques of setting and retrieving gear as well as other operational aspects of a typical long-line vessel will be described in detail for one of the more productive catchers of the fleet, the Shiratori Maru (Figure 6). This 158-gross-metric-ton vessel was built in 1949 at a cost of about 30 million yen (approximately US$83,000 at present exchange rates). Specific details of her dimensions and propulsion machinery are given in Table 2.

Table 2 - Dimensions and Mechanical Equipment of the Shiratori Maru

Gross tonnage - 158.21 metric tons	Fresh water capacity - 11.79 metric tons
Over-all length- 29.5 meters (96.8 ft.)	Maine engine - 400 h.p., 4 cycle, 6 cyl. Diesel
Beam - 6.1 meters (20 ft.)	Auxiliary engine - 60 h.p., 4 cycle Diesel
Depth - 3.05 meters (10 ft.)	Generators - 1-40 kw., 1-3 kw. generator
Fuel capacity - 58.4 metric tons	Refrigeration equipment - 1-8.5-metric ton refrigeration machine

The Shiratori Maru had a complement of 27 men, the largest crew of any of the catchers; crews on other long-line vessels numbered from 18 to 25. The actual master of the vessel was the master fisherman and not the captain. On some ships the duties of captain and master fisherman are fulfilled by one man, but in most cases, these two positions are held separately. The former is usually held by a young man who has qualified for a license as recently required by Japanese maritime regulations, and the latter is held by an older, experienced fisherman. All responsibilities connected with the navigation of the Shiratori Maru to nd from the fishing grounds and the keeping of necessary logs and records were delegated to he captain, while the master fisherman not only determined when and where to fish, ut assumed complete command when fishing began. The captain at this time was rel-gated to the position of an ordinary fisherman. Major decisions affecting vessel perations were made by the master fisherman who also maintained discipline among he crew.

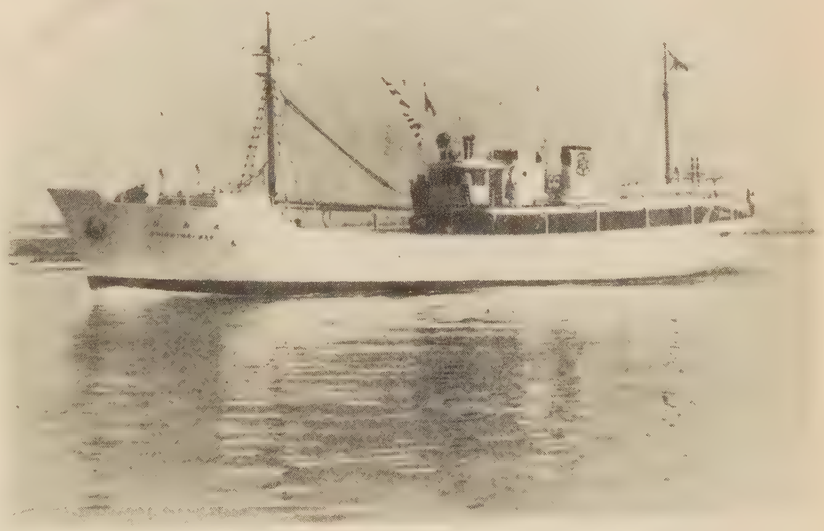


FIGURE 6 - THE SHIRATORI MARU, A JAPANESE TUNA LONG-LINER.

As is common practice among most long-line vessels, the baskets of long-line ar and floats aboard the Shiratori Maru were stowed behind the wheelhouse on the boat deck. Bamboo poles and light buoys were kept in racks located in the main deck passageways.

When ready to make a set, bait, either frozen sardines (Sardinia melanostica), or sauries (Colalabis saira), or both, was brought aft to the stern from the forward bait-storage hold. The work of assembling, baiting, and setting the long lines from the stern then commenced. The sequences of preparing and setting long lines and the work done by the crew members can probably be better understood by referring to the diagram in Figure 7. The corresponding numbers given below outline the duties of each crew member participating in the setting operation. As illustrated in the diagram, the *Shiratori Maru* had an outboard fishing rack for pole-and-line fishing which served as a platform for setting long-line gear. A wooden table was inclined from the boat deck to the stern rail to bring the gear below.

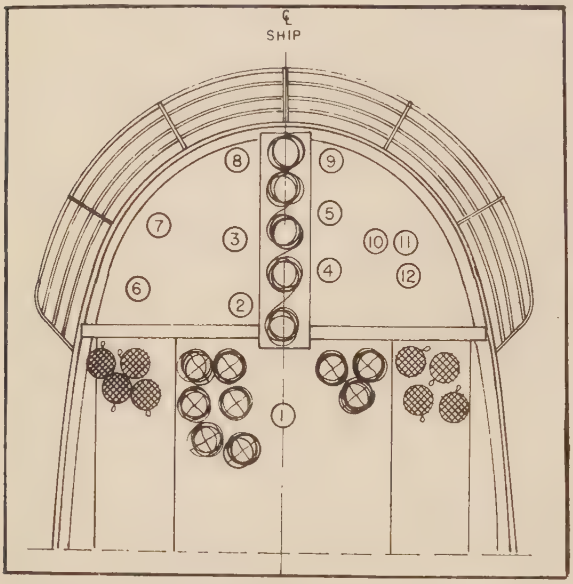


FIGURE 7 - DIAGRAM SHOWING USUAL POSITIONS OF THE FISHERMEN WHEN SETTING LONG-LINE GEAR FROM THE STERN OF THE SHIRATORI MARU.

MAN NO. 1 - UNTIES SLING HOLDING INDIVIDUAL BASKETS TOGETHER AND SLIDES LOOSE BASKETS BELOW ON WOODEN TABLE; ALSO PASSES GLASS FLOATS TO NO. 6; MAY BE ASSISTED BY ANOTHER MAN.

MAN NO. 2 - SHOVES BASKETS ALONG TABLE AND TIES HEAD OF ONE BASKET TO TAIL OF ANOTHER, THUS JOINING BASKETS.

MAN NO. 3 - UNCOILS FLOAT LINE WHICH IS ON TOP OF EACH BASKET, PASSES FREE END TO MAN NO. 7, AND STANDS BY WITH REMAINDER OF COIL; THROWS FLOAT LINE OUT WHEN MAN NO. 7 LETS FLOAT AND POLE OVERBOARD.

MAN NO. 4 - FREES TUCKED-IN HOOKS FROM COILS (LEADER AND "SEKIYAMA") AND BAITS HOOKS.

MAN NO. 5 - ASSISTS IN BAITING.

MAN NO. 6 - TIES GLASS FLOATS TO BAMBOO POLES AND PASSES POLES TO MAN NO. 7.

MAN NO. 7 - RECEIVES END OF FLOAT LINE FROM MAN NO. 3 AND TIES TO BAMBOO POLE WITH FLOAT ATTACHED; THROWS COMBINATION OVERBOARD AT BEGINNING OF EACH BASKET IN COORDINATION WITH MAN NO. 3

MAN NO. 8 - THROWS OUT COILS OF MAIN LINE.

MAN NO. 9 - THROWS OUT BAIT HOOKS AND BRANCH LINES.

MEN NOS.
10 AND 11 - BREAK OUT BAIT FROM BOXES AND SEPARATE INTO INDIVIDUAL FISH, DISCARDING POOR ONES.

MAN NO 12
AND OTHERS- ASSIST WITH BRINGING LIGHT BUOYS AFT AND TYING ON LIGHT BUOYS AS REQUIRED; RENDER GENERAL ASSISTANCE AND SERVE AS RELIEF.

A basket of gear is set as follows: (1) the glass float and bamboo pole to which is tied the float line of the basket is thrown overboard to starboard as the vessel is under way; (2) the section of main line following the float line is cast directly astern; (3) a baited branch line is then cast to port and the main line following is cast to stern again. The procedure is repeated until the entire basket of gear has been laid. An extra float line and large marker flag is used to begin the first basket of a set and to end the last basket.

Whenever possible gear is set along a straight course. The baskets are laid
hile the vessel is fully under way, the speed varying from 6 to 8 knots. The Shira-
ori Maru usually set 400 baskets of gear daily and required from 3½ to 4 hours to
et the lines into the water, an average of about half a minute being required per
asket. The actual distance travelled by the vessel was about half the total length
the main line because of the slack allowed for sag and adjustment of the gear to
urrent forces. Setting usually commenced be-
ore sunrise at about 3 a.m. and was completed
y 7:00 a.m. at the latest. The vessel then
ither drifted for several hours within sight
the flag marking the end of the set or head-
d back up the line of gear. The decision to
emain at the end of the set or to return to
he head was made by the master fisherman and
as determined largely by the direction in which
he following set was to be made and noon catch
eports of other long-line vessels. If, for ex-
mple, a set was made in a westerly direction
nd the plan was to fish in this general direc-
ion, the vessel returned to the head of the
et. After the job of retrieving the gear was
ompleted, there was time enough for the short
un to the next day's fishing area. However,
reports hinted that there was better fishing
the east, the plan of operation was altered
ccordingly. The vessel would pick up the gear
rom the end of the line set last after allowing
e gear to fish a while, thus reversing the di-
ection of the sets.

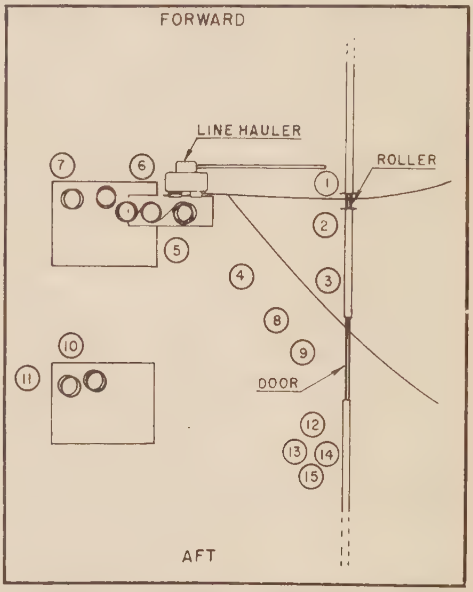


FIGURE 8 - DIAGRAM SHOWING USUAL POSITIONS OF THE FISHERMEN WHEN RETRIEVING LONG-LINE GEAR.

When returning to the head of a set, a watch was continually kept to see whether
sh had been caught on any of the branch lines. If there were signs of captured
sh, the basket or baskets were taken in without untying them from the main set.
e fish were removed, and the branch lines were rebaited and returned to the water.
This not only prevented fish from being damaged by sharks but increased the efficiency of the gear.

IGURE 9 - RETRIEVING LONG-LINE GEAR ABOARD THE
SHIRATORI MARU. NOTE THE CONSTRUCTION OF THE
LONG-LINE HAULER. ROPE SLINGS FOR BUNDLING
INDIVIDUAL BASKETS ARE PILED UP BEHIND THE
HAULER.

The laborious task of picking up the long lines usually started around noon and continued without stop until midnight. The average time required to bring in 400 baskets of gear was about 12 hours, but varied from 10 to 14 hours depending upon the number of fish that were caught.

In picking up gear, the vessel was kept constantly under way at a speed of two to three knots. The necessary maneuvering required to maintain the ship at a 15°-45° angle to the main line required close coordination between the bridge and engine room, and a bell system was rigged between these two stations to expedite communications. The usual procedure was to run the engine intermittently to approximate the speed with which the line could be brought in. Reverse was seldom used. Figures 8 and 9 show the position of the crew members when recovering gear from the head of a set. The duties of individuals and sequences of handling are:

MAN NO. 1 - HANDLES CLUTCH OF LINE HAULER AND REGULATES SPEED AT WHICH MAIN LINE IS TAKEN IN; WATCHES DIRECTION FROM WHICH MAIN LINE IS COMING AND GUIDES MAN AT WHEEL BY HAND SIGNALS.

MAN NO. 2 - WATCHES MAIN LINE AS IT COMES IN AND PASSES BRANCH AND FLOAT LINES OVER ROLLER TO MAN NO. 3 AS KNOTS GO THROUGH LINE HAULER; ADJUSTS ROLLER TO DIRECTION OF LINE.

MAN NO. 3 - COILS LEADER AND "SEKIYAMA" AND TUCKS HOOK AROUND THIS COIL, THEN COILS PART OF COTTON SECTION OF BRANCH LINE AND HANDS ALL TO MAN NO. 4; ALSO COILS PART OF FLOAT LINE AFTER BAMBOO POLE AND FLOAT HAVE BEEN REMOVED.

MAN NO. 4 - FINISHES COILING BRANCH AND FLOAT LINES AND GIVES COILS TO MAN NO. 6.

MAN NO. 5 - WATCHES MAIN LINE AS IT COMES THROUGH LINE HAULER AND WHEN SECTION OF MAIN LINE BETWEEN BRANCH LINES IS COILED, MOVES COIL FROM BENEATH LINE HAULER TOWARD MAN NO. 6; WHEN BRANCH LINE HAS BEEN PLACED ATOP MAIN LINE BY MAN NO. 6, TAKES NEXT SECTION OF MAIN LINE ALREADY COILED AND PLACES IT ATOP BRANCH LINE; REPEATS UNTIL BASKET IS COMPLETE; UNTIES TAIL OF BASKET FROM HEAD OF NEXT BASKET.

MAN NO. 6 - TAKES COILED BRANCH LINE FROM MAN NO. 4 AND WHEN SECTION OF MAIN LINE HAS BEEN MOVED FROM BENEATH LINE HAULER BY MAN NO. 5, PLACES BRANCH LINE ATOP THIS COIL; COILS FLOAT LINE, WHICH IS LAST ATTACHED LINE OF BASKET TO COME IN, AND HANDS TO MAN NO. 7.

MAN NO. 7 - ARRANGES COILS OF MAIN LINE, BRANCH LINES, AND FLOAT LINE IN ORDER, BUNDLES BASKET TOGETHER WITH A FOUR-PIECE COTTON ROPE SLING AND TAKES BASKET AFT FOR STOWAGE.

MAN NO. 8 - PULLS IN BAMBOO POLE AND BUOYS; UNTIES FLOAT LINE FROM POLE.

MAN NO. 9 - ASSISTS MAN NO. 8 IN PULLING IN POLES AND BUOYS; REMOVES GLASS FLOATS.

MEN NOS.
10 AND 11 - REARRANGE BASKETS NOT PROPERLY COILED; TIE IN BRANCH LINES PREVIOUSLY REMOVED AND REPLACE WORN LEADERS; ASSIST MEN NOS. 2, 3, AND 4 WHEN NECESSARY.

MEN NOS.
12, 13, 14,
15, AND
OTHERS - BRING IN FISH; GUT AND STORE CATCHES; STOW FLAGS, BUOYS AND GEAR; ACT AS RELIEF.

The sequence in which a basket of gear is brought aboard is reverse of that which it is set; that is, (1) the main line is coiled as it comes aboard, and (2 branch line is taken in and placed on top of the main line. This is repeated un all five branch lines have been retrieved. The basket is completed by bringing the float line. The head of the basket is then untied from the tail of the next basket and the basket is bundled and stowed.

Fish hooked on branch lines were brought in quickly by two or three of the members and gaffed when alongside. They were then pulled aboard through the doo cut in the rail, killed if necessary, and immediately eviscerated if of a specie other than yellowfin or albacore tuna. The landing of larger marlins and sharks frequently gave considerable trouble and, furthermore, tangled the lines badly. These fish, as well as any tuna which were taken alive, were killed by the fishe men who beat them on the head with large wooden mallets. Fish were usually stor elow in ice immediately after capture, but occasionally when fishing was productive nd the crew was busily engaged in hauling in both fish and lines, the catch was alowed to lay on deck for about fifteen to thirty minutes before storage. During the fternoons when air temperatures were high, the practice was to ice the fish as soon s practicable.

The work of retrieving and stowing gear and disposing of the catch required the mmediate services of about 18 men, and everyone aboard except the wireless operator articipated in the operations at some time during the day. No regular shifts were mployed, and the men took turns at various jobs. The individual fishermen conseuently worked from 16 to 18 hours per day when on the fishing grounds. What little est they obtained was either during the few hours after the work of taking in gear ad been completed or when a set was finished. Longer respites were enjoyed when he catcher proceeded to and from the mothership or when a shift was made in fishing rounds.

Total Landings of Fish: From June 17, 1950, when fishing started, to the close f processing operations on September 2, deliveries of fish to the mothership by ong-line vessels totaled approximately 7,683,000 pounds. Many of the catchers coninued to fish after making their last trips to the mothership and did not cease perations until September 5. These later catches were landed directly in Japanese orts and amounted to over 435,000 pounds. The total catch, therefore, of the first ong-line fleet in 79 days of operation in waters south of the Caroline Islands was bout 8,118,800 pounds (Table 3) with a reported landed value of 145,493,500 yen about US$404,000). To catch this quantity of fish, 1,417 sets of gear were made the vessels, equivalent, if joined in one continuous line, to 93,000 miles of ne, more than enough to encircle the world three and a half times. Incidental tches of the smaller tuna were made by pole-and-line gear, but these were of minor antity.

Table 3 - Total Catch, by Species, of the First Japanese Tuna-Mothership Expedition, June-September, 1950[1]

Species	Quantity Caught
	Lbs.
Yellowfin tuna (*Neothunnus macropterus*)	4,574,358
Big-eyed tuna (*Parathunnus sibi*)	699,014
Albacore (*Thunnus germo*)	65,378
Bluefin tuna (*Thunnus orientalis*)	3,430
Skipjack (*Katsuwonus pelamis*)	6,968
Black marlin (*Makaira mazara*)	1,760,389
White marlin (*Makaira marlina*)	48,182
Striped marlin (*Makaira mitsukurii*)	1,229
Sailfish[2] (*Istiophorus orientalis*)	28,160
Swordfish (*Xiphias gladius*)	13,656
Shark	895,022
Others[3]	23,048
Total	8,118,834

[1] STATISTICS PROVIDED BY THE JAPANESE FISHERY AGENCY AND CONVERTED TO POUNDS, USING THE CONVERSION FACTOR OF 8.27 LBS. = 1 KAN.

[2] INCLUDES SHORT-NOSED MARLIN (*TETRAPTURUS BREVIROSTRIS*).

[3] INCLUDES BARRACUDA (*SPHYRAENA ARGENTEA*), WAHOO (*ACANTHOCYBIUM SOLANDRI*), AND DOLPHIN (*CORYPHAENA HIPPURUS*).

Composition of Catch: Fish included in the catches may be conveniently sepa-ted into four general categories: the tunas, spearfishes, sharks, and miscellaneous varieties of fish. Of these, the tunas and spearfishes, being commercially th most valuable, were the species most sought after by the fishermen.

The tunas were represented in the catch by the yellowfin tuna (*Neothunnus macropterus*), big-eyed tuna (*Parathunnus sibi*), oceanic skipjack (*Katsuwonus pelamis*) albacore (*Thunnus germo*), and the bluefin tuna (*Thunnus orientalis*). The yellowfin tuna was by far the most abundant of these five species, comprising over 50 percent of all the fish landed. Catches of this species occurred throughout the area fishe from 1° N. latitude to 9° N. latitude and from 143° E. longitude to 160° E. longitude. The full range of this particular species was not covered by the fishing vessels, but fishing results seemed to verify the observation that in western equatorial waters of the northern hemisphere, yellowfin tuna are most concentrated in the zone between the Equator and 5° N. latitude.

Individual yellowfin captured by long lines ranged in size from 80 centimeters to 160 centimeters with fish of about 130 centimeters, averaging from 80 to 90 pounds. The largest individuals weighed up to 150 pounds while smaller fish, usual those caught at the surface by pole-and-line gear, weighed but a few pounds.

Of the total tuna catch, the big-eyed tuna (*Parathunnus sibi*) ranked second to the yellowfin tuna on the basis of weight and number. This species apparently prefers a more temperate distribution than the yellowfin for it was generally caught at deeper levels and appeared to increase in abundance north of 5° N. latitude. Li the yellowfin, the big-eyed tuna varied in size from small individuals of about 5 pounds in weight to large fish of over 150 pounds.

From all reports, the oceanic skipjack (*Katsuwonus pelamis*) abounds in waters bordering the many islands found in the western Pacific Ocean and is also found in offshore waters. Being more of a surface-inhabiting fish, however, the number of fish of this species caught by long-line vessels was small in contrast to the catc of the deeper-living yellowfin and big-eyed tuna. Schools of skipjack were often found to be congregated beneath the glass floats of the long lines and these schoo were fished by pole and line, using artificial lures.

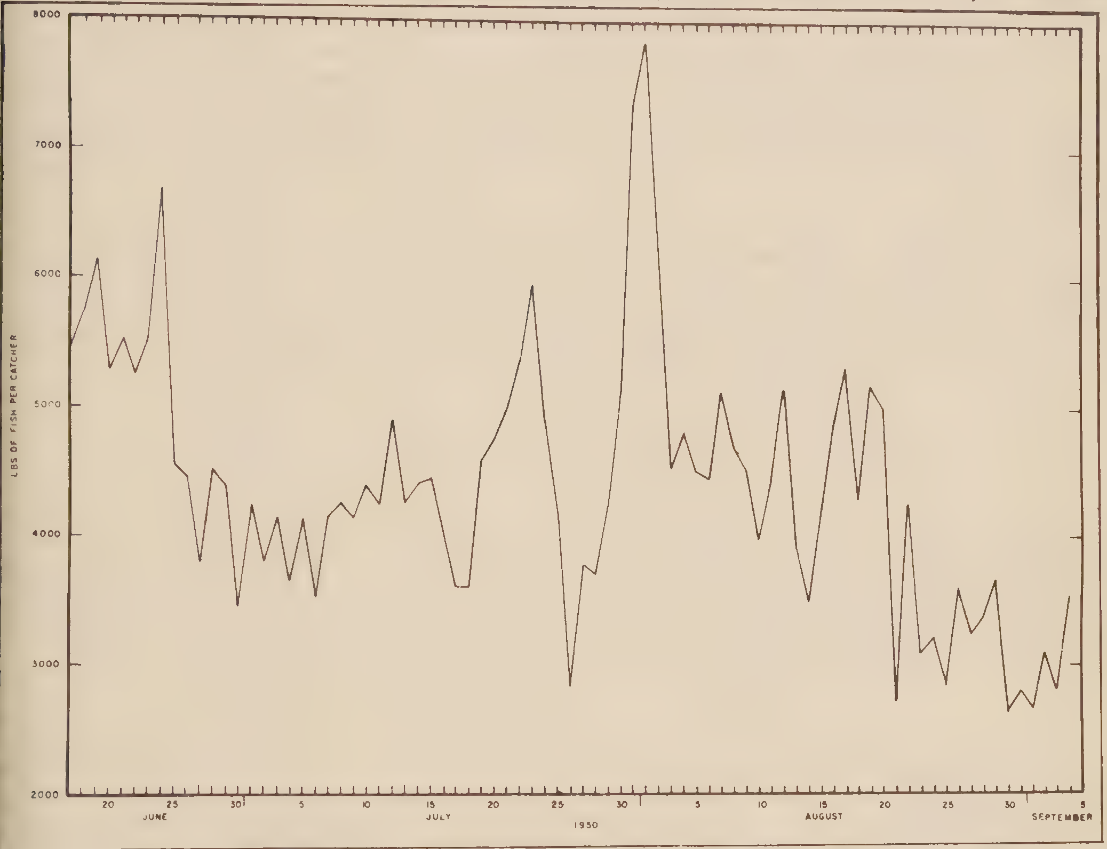
Albacore (*Thunnus germo*) and bluefin tuna (*Thunnus orientalis*), which are species normally confined to temperate waters, comprised a small percentage of the total catch and were caught throughout the season.

The spearfishes consisted of the black marlin (*Makaira mazara*), white marlin (*Makaira marlina*), short-nosed marlin (*Tetrapterus brevirostris*), striped marlin (*Makaira mitsukurii*), sailfish (*Istiophorus orientalis*), and the true swordfish (*Xiphias gladius*). On the basis of landings by weight, the black marlin was the most abundant of these species and was second to the yellowfin tuna. Some individuals of black marlin weighed upwards of 1,000 pounds.

Sharks brought in by the fishermen were not identified, but some species of these families were noted: Carcharinidae, Galeorhinidae, Alopiidae, Sphyrnidae an Lamnidae. Other fish delivered to the mothership were barracuda (*Sphyraena argent* wahoo (*Acanthocybium solandri*), and an occasional dolphin (*Coryphaena hippurus*).

Variations in Fishing Success: Throughout the season and over the entire fis ing area, the daily catches made by the fishing vessels of the expedition fluctua markedly. Figure 10 shows the average catch per boat reported for each day's oper tions. Fishing was generally good when operations first commenced. As the peak c productive fishing said to be associated with May and June passed and the catcher fleet was augmented, catches fell to an average of from 2-2½ metric tons per boat

aily. With the eastward movement of the expedition and access to new grounds, the
atches improved. Excellent fishing was experienced for several days during mid-
uly in waters adjacent to Kapingamarangi Atoll (1° 05' N.-154° 45' E.), from about



IGURE 10 - AVERAGE CATCH OF FISH PER DAY PER CATCHER BASED ON DAILY REPORTED LANDINGS.
(REFER TO FIGURE 2 FOR GENERAL AREA IN WHICH CATCHES WERE MADE DURING THE SEASON.)

3° to 154° E. longitude and between 1° and 2° N. latitude. The average landings
r vessel decreased inexplicably thereafter to less than 1½ tons per day as a ma-
rity of the catchers continued to fish in the same general area. In late July
d early August, fishermen encountered the best fishing of the season in the area
the east of Kapingamarangi Atoll (between 156° and 158° E. longitude), and in
e same parallels of latitude where good fishing was previously experienced (1° to
N. latitude). Judging from reported current drifts, this latter zone was prob-
ly within the equatorial countercurrent and close to its southern border. Here,
me vessels caught as much as 8 tons per day's fishing and the highest reported
dividual catch for a single operation was 11 tons, mostly yellowfin tuna. Catches
adually fell to lower levels in middle and late August with a daily average below
tons per boat at the close of the season as the expedition shifted northward out
the productive areas in anticipation of the trip home.

The "catch per unit of effort" for the Japanese long-line fishery is usually
pressed as the number of fish caught per 100 hooks fished per day. This is a
eful index to the success of fishing at a particular time. Data of this nature
ve been compiled for the prewar Japanese long-line fishery in equatorial waters
Nakamura (1943). Based upon an analysis of fishing boat logs and research ves-
l records for a period of several years, Nakamura reported an average of 6.05 fish

(tunas and spearfishes) for each 100 hooks set in the area between 0° and 5° N. la tude and between 130° and 180° E. longitude. In contrast, vessels of the 1950 expedition averaged 3.23 tunas and spearfishes for each 100 hooks fished, the averag for all species being 3.97. These figures do not include fish damaged by sharks which usually comprised from 5-10 percent of the total number of fish hooked. Th highest catch ratio reported for one day's fishing was 17 fish per 100 hooks. Al though these data are not comparable with Nakamura's figure in terms of space, tim and other factors, it illustrates that the expedition vessels did not achieve as h an average catch per 100 hooks as that previously reported for the same general ar of operations.

This apparent difference in the success of fishing was attributed by the fish ermen chiefly to a decreased abundance of tuna stocks despite the fact that these fish were not subject to exploitation during World War II. Estimates of the decrease in abundance averaged 20 percent among those fishermen interviewed, but ran as high as 50 percent. Causes for the decrease were believed to be:

(1) VARIATIONS IN ENVIRONMENTAL CONDITIONS
(2) EFFECTS OF THE WAR AND THE ATOM BOMB EXPERIMENTS
(3) DEPLETION IN STOCK THROUGH OVERFISHING IN PREWAR YEARS

The fishermen were inclined to think that changes in hydrographic conditions were probably most responsible for the lower catches made by the expedition. Adversity in success of fishing was also ascribed to restrictions in latitude of movement by the catchers. It should be noted in this regard that very few applications were made for permission to fish beyond the specified 200 miles from the mothership.

MOTHERSHIP VESSEL OPERATIONS

The Mothership: The Tenyo Maru No. 2, a 10,619-gross-metric-ton vessel, meas uring approximately 550 feet in over-all length (Figure 11), was primarily designe to handle whale meat. It was selected to accompany the tuna expedition as a mothership bec her facilities could be used t freeze tuna and other fish at The storage space of this vess was sufficiently large to handl the tonnage of fish expected f the season's fishing. Further it was idle during the summer participation in the tuna oper tion would not prevent the ves from engaging in the winter's Antarctic whaling. For this p ticular assignment no changes made in the existing shipboard equipment because of the trial nature of the expedition and t lack of time for preparation. only major addition was an ice crusher which was installed on the main deck. With this exception, the details o construction for the mothership are given in Figure 12.

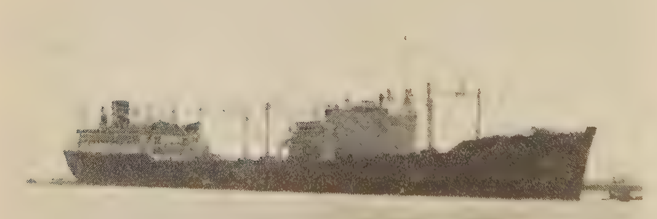


FIGURE 11 - THE MOTHERSHIP, TENYO MARU NO. 2.

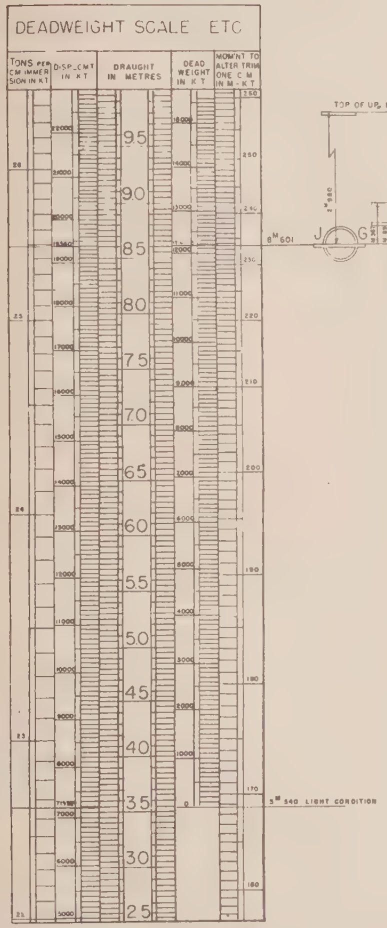
A total of 171 persons was carried by the Tenyo Maru No. 2, including the shi crew, workers, office and supervisory personnel, and the various observers require

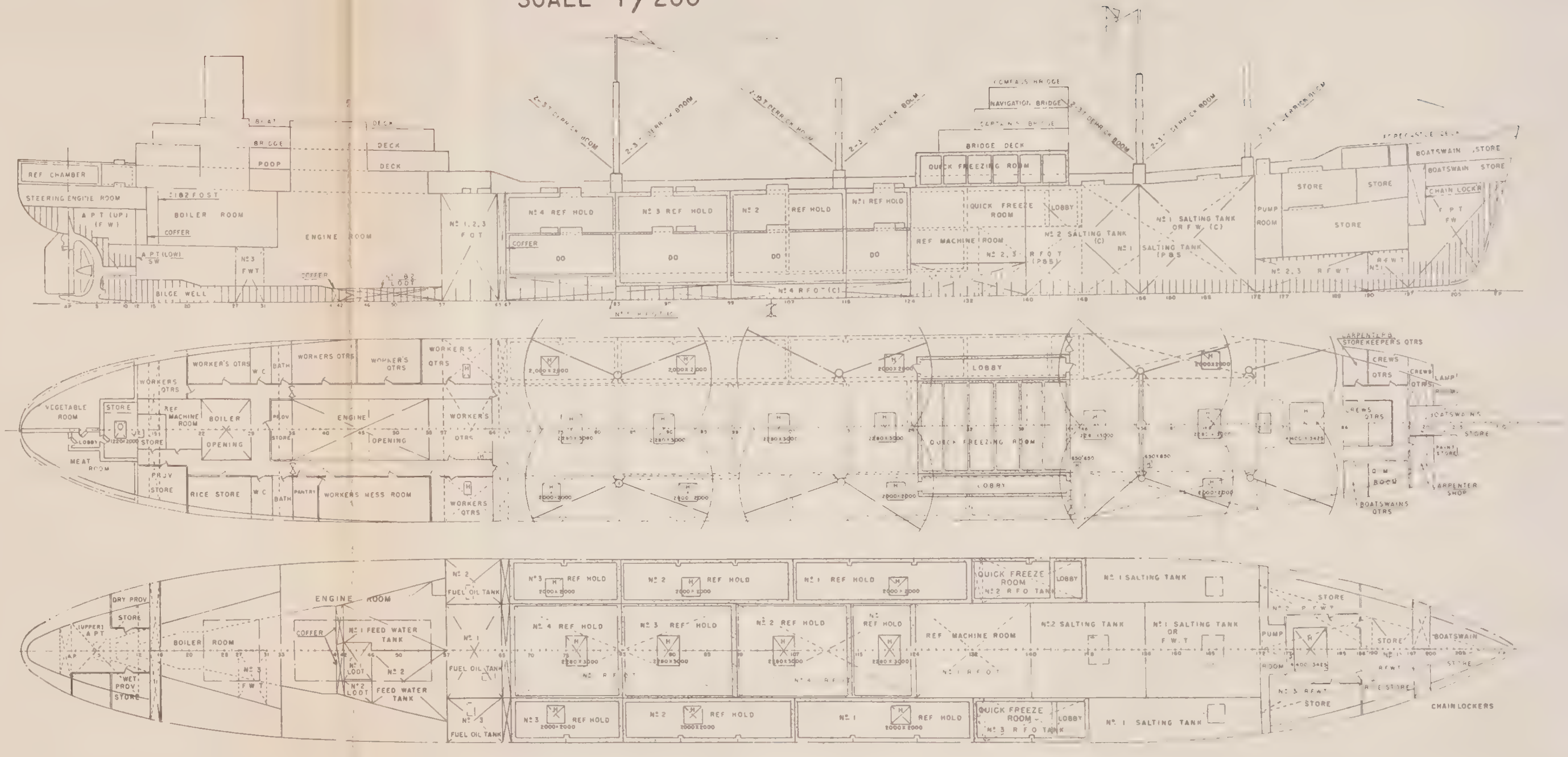
FIGURE 12 - PLAN OF M.S. TENYO MARU NO. 2 USED AS A TUNA MOTHERSHIP DURING THE FIRST EXPEDITION OF THIS TYPE IN THE EQUATORIAL PACIFIC OCEAN AFTER WORLD WAR II.

M.S. TENYO MARU No.2

CAPACITY PLAN & DEADWEIGHT SCALE

SCALE 1/200





CAPACITY OF STORES

NAME OF STORE	FRAME Nº	CAPACITY CUB METRE	L C G FROM ⊕	V C G ABV B L
BOATSWAIN STORE (UP DECK)	197-FE	119,644	-72 026	14 976
LAMP ROOM (UP DECK)	201-205	17.240	70 846	10 696
PAINT STORE (UP DECK)	201-205	20 290	-70 850	11 303
BOATSWAIN STORE (2ND DECK)	200-FE	76 908	-71 604	12 535
STORE (2ND DECK)	188-197	93.107	-64 250	11 534
RICE STORE (2ND DECK)	188-197	93 107	-64 250	11 534
STORE (2ND DECK)	174-188	136 558	-56 427	10 809
" "	174-188	136 558	-56.427	10 809
" (BRIDGE DECK)	143-146	8.439	-30 315	16 530
	143-146	8 439	-30 315	16 530
"	134 39	32 148	24 520	6 530
	32½ 136½	2 700	22 905	16 530
" "	15 20	13 896	65 525	15 930
"	17 20	11 573	64 840	15 930
DAILY PROV'N STORE (POOP DECK)	31⅔-35	17.976	53 580	15 485
	31⅔ 35	17 976	53 580	15 485
PROVISION STORE (UP DECK)	31⅔-35	35 952	53 560	13.175
RICE STORE (UP DECK)	20-29	59.818	60 181	13 455
PROVISION STORE (UP DECK)	12-20	55.268	66 358	13 658
DRY PROV'N STORE (2ND DECK)	7-14	32 690	69 981	11 404
WET PROV'N STORE (2ND DECK)	7-14	32.690	69 981	11 404
REF ROOM (VEG.) (2ND DECK)	12-AE	89.820	74 590	13 928
REF ROOM (MEAT) (2ND DECK)	12-AE	75.760	74 622	13 931
STORE	174 197	712 010	-59 189	6 586
" (UP DECK)	2 7	27 232	67 580	13 450
" (2ND DECK)	AP-7	32 27	74 15	11 525
TOTAL		1 979 070		

CAPACITY OF FUEL OIL TANKS S.G 0 935

NAME OF TANK	FRAME Nº	CAPACITY		L C G FROM ⊕	V C G ABV BL.
		CUB M	TON		
Nº 1 FUEL OIL TANK	57-65	695 655	650 437	32 540	5 804
Nº 2 " " "	" "	315 311	294 816	32 489	6 182
Nº 3 " " "	" "	315 311	294 816	32 489	6 182
Nº 1 RESERVE FUEL OIL TANK	124-140	412 476	385 665	-20 815	1 773
Nº 2 " " " "	133½-148	393 037	367 490	-27 437	3 887
Nº 3 " " " "	" "	393 037	367 490	-27 437	3 887
Nº 4 " " " "	99-124	281 099	262 828	-5 235	0.800
Nº 5 " " " "	67-99	515 036	481 559	16 425	0.800
Nº 1 F O SETTLING TANK	14-16	38 436	35 938	67 305	9 917
Nº 2 " " "	" "	38.436	35 938	67 305	9 917
TOTAL		3397 834	3176 977		

CAPACITY OF WATER TANKS S W 1025 F W 1000

NAME OF TANK	FRAME Nº	CAPACITY		L C G FROM ⊕	V C G ABV BL
		CUB M	TON		
Nº 1 RESERVE F W TANK	190-197	68 830	68 830	-64 895	2 665
Nº 2 " " "	172-190	184 109	184 109	-56 413	2 207
Nº 3 " " "	" "	184 109	184 109	-56 413	2 207
Nº 1 FEED WATER TANK	42-57	90 456	90 456	41 028	0 844
Nº 2 " "	46-57	73 767	73 767	40 037	0 845
Nº 3 F W TANK	27-31	51 320	51 320	56 795	1 455
Nº 1 SALTING T. OR F W T	156-172	445 689	445 689	-45 194	6 063
FORE PEAK TANK (F W)	197 213	196 900	196 900	[illegible]	7 235
AFT PEAK TANK (UP) (F W)	A P 12	8 860	8 860	72 210	8 825
" " (LOW) (S W)	4 12	22 088	22 640	[illegible]	4 909
TOTAL		2 436 28	2436 680		

CAPACITY OF REF HOLD

NAME OF REF HOLD	FRAME Nº	CAPACITY CUB METRE	L C G FROM ⊕	V C G ABV BL
Nº 1 REF HOLD C (UP)	115-124	173 664	-11 315	9 205
" " " C (LOW)	" "	233 804	-10 672	4 565
" " " P (UP)	107-132	216 548	-9 815	9 205
" " " P (LOW)	" - "	275.001	-9 815	4 963
" " " S (UP)	" - "	216 548	9 815	9 205
" " " S (LOW)	" - "	275 001	-9 815	4 963
Nº 2 REF HOLD C (UP)	99-115	335 566	1 815	9 205
" " " C (LOW)	" - "	555 873	-1 815	4 413
" " " P (UP)	83-107	209 312	7 305	9 205
" " " P (LOW)	" - "	266 082	7 305	4 963
" " " S (UP)	" - "	209 312	7 305	9 205
" " " S (LOWER)	" - "	266 082	7 305	4 963
Nº 3 REF HOLD C (UP)	67-83	335 566	10 345	9 205
" " " C (LOW)	" - "	555 873	0 345	4 413
" " " P (UP)	" - "	134 176	22.505	9 205
" " " P (LOW)	" - "	169 383	22 505	4 963
" " " S (UP)	" - "	134 176	22 505	9 205
" " " S (LOW)	" - "	169 383	22 505	4 963
Nº 4 REF HOLD C (UP)	" - "	326 714	22 305	9 205
" " " C (LOW)	" - "	424 488	22 305	4 963
TOTAL		5,482 552		

PRINCIPAL PARTICULARS

LENGTH OVER ALL		M	160.824
LENGTH BETWEEN PERPENDICULARS		M	152 823
BREADTH MOULDED		M	20 000
DEPTH MOULDED		M	11 500
TONNAGE	GROSS TONNAGE	T	[illegible]
	NET TONNAGE	T	[illegible]

CAPACITY OF SALTING TANKS

NAME OF TANK	FRAME Nº	CAPACITY CUB METRE	L C G FROM ⊕	V C G ABV BL
Nº 1 SALT'G T OR FWT (C)	56 72	[illegible]	[illegible]	[illegible]
Nº 1 SALTING TANK (P)	48 72	769 86	40 099	6 983
Nº 1 " (S)	48 72	769 86	40 099	6 983
Nº 2	40 56	327 06	-32 975	5 387
TOTAL		4,253 342		

CAPACITY OF L O O TANK S G 0 920

NAME OF TANK	FRAME Nº	CAPACITY		L C G FROM ⊕	V C G ABV BL
		CUB M	TON		
NO 1 LUB O O TANK	[illegible]	8 191	5 644	45 455	[illegible]
Nº 2		4 782	5 3 8	[illegible]	[illegible]
TOTAL		23 8	2 962		

THROUGH THE COURTESY OF
TAIYO FISHING CO TOKYO, JAPAN

under the provisions of the SCAP directive. Table 4 shows the classification of shipboard personnel by activity and number.

Table 4 - Personnel Aboard the Mothership, Tenyo Maru No. 2

Ship's Complement

Total - 82

Deck Department	Steward's Department	Engine Department
Captain	13 cooks, cook helpers, mess boys	Chief engineer
5 mates		6 assistant engineers
20 able-bodied seamen		26 firemen, oilers, water tenders, wipers
3 radio operators	Medical Department	2 refrigeration engineers
	Ship's doctor	1 refrigeration assistant
	Medical assistant	

* * * * * * *

Company Personnel	Observers and Others
Total - 83	Total - 6
General Manager	SCAP representative
2 assistant managers	Representative, High Commissioner of the Trust Territories
Interpreter	2 Japanese Government inspectors
25 deck workers	Japanese biologist
44 cold storage workers	Japanese news reporter
3 office workers	
5 workers assigned to Steward's Dept.	
1 worker assigned to Medical Dept.	
Ship repair specialist	

General Supervision: The general manager was in charge of all work connected with the handling, processing, and freezing of fish aboard the mothership. He was also responsible for conducting business with the fishermen. The actual performance of these duties was largely delegated to two assistants. One assistant manager took charge of deck operations, and the other served as a liaison man between the management and the fishermen. Control over the movements of the mothership, and consequently of the expedition as a whole, was also exercised by the general manager, subject to the approval of Japanese Government representatives aboard.

Unloading and Servicing of Catcher Boats: The mothership did not call upon the deployed catchers to pick up fish. Instead, an unloading schedule was set up based upon the freezing capacity of the mothership whereby two or three vessels returned daily to discharge their catches. This system of rotation allowed the catchers to stay out from seven to eight days per trip. Quite frequently, however, it was impossible to unload the vessels immediately because of the lack of freezer space or breakdowns in the refrigeration equipment. This, coupled with the fact that only one vessel could be unloaded at a time, often resulted in a backlog of vessels. When this happened an added strain was placed upon the mothership workers and the catcher fishermen were dissatisfied because of the unnecessary loss of valuable fishing time. Catchers sometimes had to wait as long as 24 hours before they were able to tie up to the mothership. The fishermen felt that a more realistic and flexible timetable could have been maintained by scheduling the catchers ac-

REFRIGERATION:

1. Freezing fish at sea, defrosting, filleting, and refreezing the fillets: To test the proposed method of freezing fish at sea on a commercial scale, a surplus trawler was obtained by transfer from another Federal agency, and it is now being reconditioned and equipped with fish-handling and refrigeration equipment. The first commercial trial is planned for June 1951.

2. Study of fresh and frozen oysters: Darkening of oysters during frozen storage was not prevented or appreciably retarded by treating with ascorbic acid. Commercially-packed frozen oysters showed insignificant pH changes during storage. A report was submitted for publication.

3. Studies on methods of handling frozen salmon for canning: Use of frozen salmon for canning produces a slightly inferior canned product, even if the frozen fish were handled and stored under the present best conditions. A preliminary report was published.

4. Freezing pink salmon: Storage life of frozen pink salmon may be extended to 10 months or more by use of improved packaging methods, lower storage temperatures, or suitable antioxidant dips.

5. Freezing and storing Alaska shrimp and Dungeness crab: Preliminary tests indicate the quality of frozen Alaska shrimp is affected greatly by the methods of precooking and packaging. Frozen cooked crab meat in the shell stored at 0° F. was unmarketable after 60 to 90 days.

6. Palatability and cold storage life of various species of Pacific Coast rockfishes: Sebastodes alutus (long-jawed rockfish) is far superior in cold storage life and slightly superior in initial palatability to other commo species of rockfish. S. alutus is slightly superior to Sebastes marinus (Atlantic Coast ocean perch or rosefish) in cold storage life but very slightly inferior in initial palatability.

7. Preparation of a manual on the refrigeration of fish: The outline was prepared and literature references are being reviewed and assembled.

PROCESSING AND PRESERVATION:

1. Canning of "little tuna": Test packs indicate it is possible to prepare a canned product of commercial quality. A report on the project will be presented at the annual convention of the Institute of Food Technologists, June 1951.

2. Evaluation of the antibiotic "subtilin" as a preservative for fishery products: Application of subtilin to preservation of fresh cooked crab meat showed little promise. This fact coupled with adverse criticisms regarding use of antibiotics in foods by other Federal agencies and certain tra associations prompted discontinuance of this project.

3. Comparison of canned gill net-caught albacore tuna with the trol caught fish: The tuna were canned in a custom cannery where certain differen existed between the procedure used and that ordinarily employed commercially. As a result the product was not well packed and considerable scorch was preser Therefore, no definite conclusion could be drawn from the test.

ing a catcher with ice, 200-pound blocks were removed from the lower hold through the hatch next to the base of the ice crusher and lifted by winch and tongs to the bridge deck. On the bridge deck, the blocks were broken in half and fed into the rotary crusher, which was capable of crushing a ton of ice every 3½ to 4 minutes. The crushed ice passed through a metal chute into a large canvas hose, the opening of which was guided by the fishermen below so that the ice would flow directly into the catcher's fish holds. The load of ice taken for a single trip varied from 15-20 tons for catchers without refrigeration systems, and from 5-10 tons for those with a means of maintaining low temperatures in the holds.

Handling and Processing of Fish: The various operations connected with the processing of fish for freezing aboard the mothership were confined to the weather deck aft of the bridge (Figure 14). Most of this working area, which extended over 2,500 square feet or more of open space, was covered with overhead canvas tarpaulins to protect the workers and fish from the weather and to prevent diffusion of light when working at night. Deck space forward of the bridge to the forecastle was utilized only as a storage area. Figure 15 shows the general lay-out of the main deck and the manner in which fish were routed for processing.

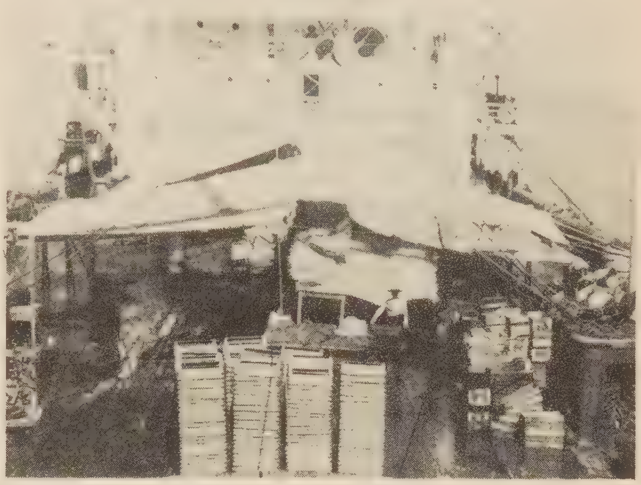


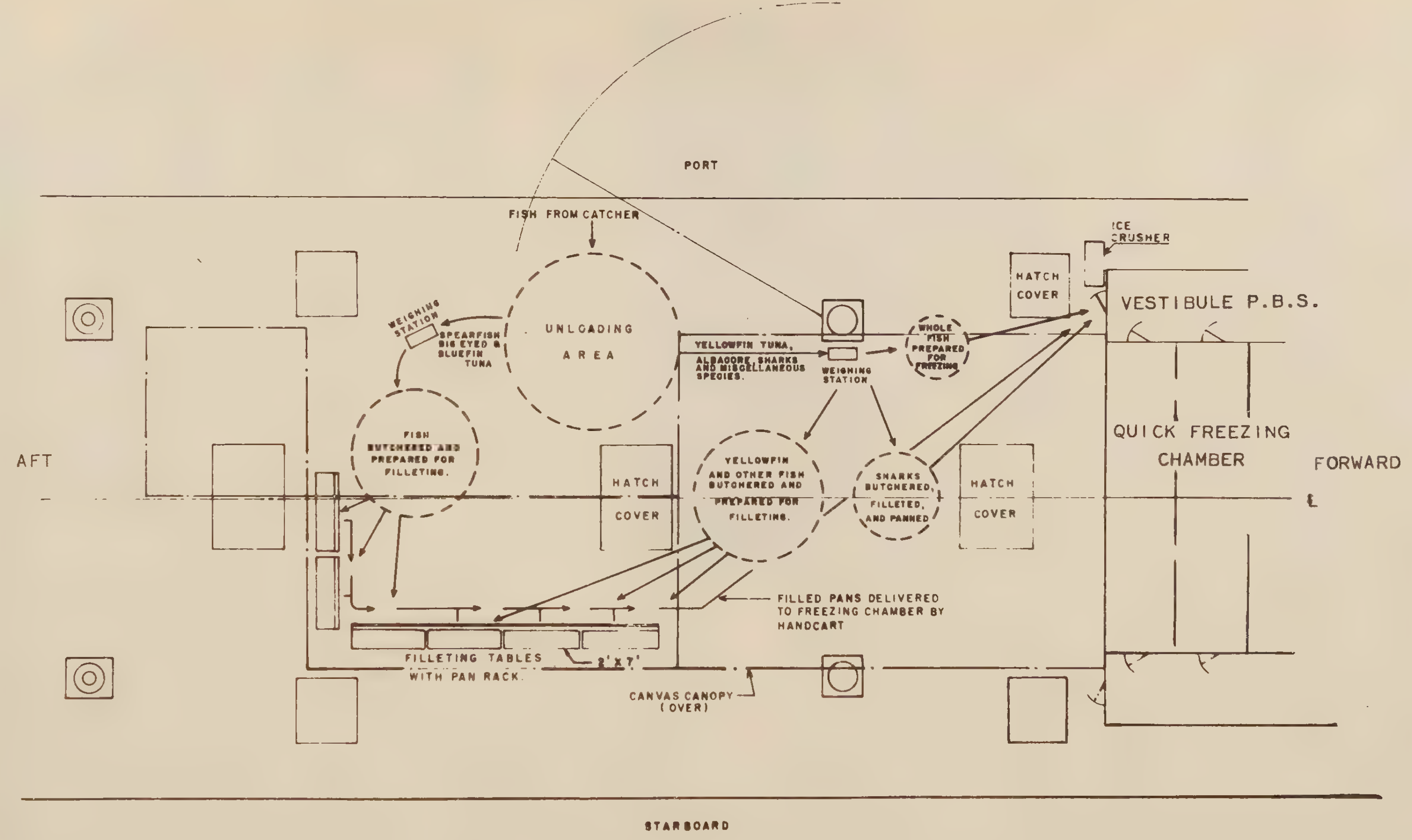
FIGURE 14 - LOOKING AFT TOWARDS THE WORKING AREA ABOARD THE MOTHERSHIP. PANS IN THE FOREGROUND ARE FOR HOLDING FILLETS.

As soon as the fish were deposited on deck, they were washed with salt water before being separated by species and taken to the scales for grading and weighing. Catcher fishermen not engaged in unloading usually assisted the three or four mothership workers n hauling the fish to weighing stations and loading them on the scales. Fish pews ere used to move fish around and the common practice of indiscriminately hooking ish with pews frequently resulted in lower grading and unnecessary wastage of fish.

Two weighing stations were set up, one fore and one aft of the unloading area. he after station, being closer to the filleting tables, was used to weigh big-eyed una, occasional bluefin tuna, and the various species of spearfishes. The forward eighing station, because of its proximity to the freezing chamber, handled fish uitable for freezing in the round, such as yellowfin, albacore, shark, and miscellaneous species of fish.

Weighing at both stations was done by means of a 500-kilogram (1,100-pound) latform scale. A wooden platform placed on the scales made it possible to weigh several fish at a time. The platform, however, was not long enough for the larger arlins, which had to be sectioned prior to weighing. Records of weights, grade, d species were kept by a company man and also by a fisherman from the catcher being unloaded.

The condition of fish delivered to the mothership was generally good with very ittle spoilage because the fishermen made liberal use of their ice and the trips ere of short duration. Salable fish was bought by the mothership management at a rice which differed for species and quality of fish. Yellowfin and albacore commanded the highest prices because of their export value. Sharks brought the lowest


PORT
FISH FROM CATCHER
ICE CRUSHER
HATCH COVER
VESTIBULE P.B.S.
WEIGHING STATION
SPEARFISH BIG EYED & BLUEFIN TUNA
UNLOADING AREA
YELLOWFIN TUNA,
ALBACORE, SHARKS AND MISCELLANEOUS SPECIES.
WEIGHING STATION
WHOLE FISH PREPARED FOR FREEZING
QUICK FREEZING CHAMBER
AFT
FISH BUTCHERED AND PREPARED FOR FILLETING.
HATCH COVER
YELLOWFIN AND OTHER FISH BUTCHERED AND PREPARED FOR FILLETING.
SHARKS BUTCHERED, FILLETED, AND PANNED
HATCH COVER
FORWARD
℄
FILLED PANS DELIVERED TO FREEZING CHAMBER BY HANDCART
FILLETING TABLES WITH PAN RACK.
2'X7'
CANVAS CANOPY (OVER)
STARBOARD

GENERAL LAYOUT OF THE MAIN DECK
WORKING AREA AND FLOW DIAGRAM
FIGURE 15

price. Quality was related to the general appearance of the fish, texture, firmness, and color of meat, and this was determined by organoleptic methods at the time of weighing by a company man. Yellowfin tuna were arbitrarily graded by condition into four and sometimes five grades; big-eyed tuna into three or four; albacore into two; marlin and other fish into two or three grades. Proportionally lower prices were paid for the poorer grades of fish. Shark prices did not change with species or quality.

Yellowfin tuna, albacore, and some of the smaller tunas were not gutted at sea like other species. At the company's request, however, gills of all yellowfin tuna were removed immediately after capture because it was believed that whole yellowfin so treated would be more acceptable for export. A monetary allowance was given the fishermen to compensate them for this loss of weight.

Shark and tuna livers were saved by all of the catcher boats and were either kept aboard each catcher or were transferred to the mothership for freezing and storage. By long-standing practice, the revenue derived from livers is divided among the fishermen. Livers derived from uneviscerated fish purchased by the company, however, did not revert to the fishermen but became company property.

After weighing, yellowfin tuna, albacore, wahoo, and small tunas suitable for freezing whole were thoroughly washed and scrubbed before being passed to the freezing chamber. Yellowfin tuna were checked for gill removal and for external wounds or abrasions which could result in their rejection when exported. Furthermore, for ease of handling, the long second dorsal and anal fins which are characteristic of mature yellowfin tuna were chopped off close to the base.

All tuna exceeding 11 inches in thickness and those not meeting quality standards for freezing as whole fish were prepared for filleting in the area immediately adjacent to the forward weighing station. Here, on the wooden deck, the fish were beheaded with cleavers, cleaned, and washed before being taken aft to the filleting tables. Except for the removal of the livers, no effort was made to utilize the viscera and heads which were thrown overboard.

Spearfish and big-eyed tuna were similarly processed for filleting near the after weighing station. Big-eyed tuna, weighing less than 10 lbs. and sections of the smaller sailfish were sometimes frozen whole depending upon the availability of shelf space in the freezers.

Sharks were cut into sections after weighing and pan-frozen for later sale to Japanese fish-cake manufacturers. The dorsal, pectoral, and caudal fins of these fish, highly esteemed by Orientals when dried, were also retained as a byproduct and frozen.

The six filleting tables were 7 feet long by 2 feet wide, with metal grates in front to serve as pan racks. Those on the starboard, usually the weather side, were sheltered by a backdrop of bamboo curtains in addition to the overhead canvas. A 200-watt lamp suspended over each table provided very poor light for night work, but the filleting tables were well lighted as compared to other areas of the deck where hazardous work, such as butchering, was often conducted in semidarkness.

The techniques used to fillet fish were essentially the same for all filleters and a skilled worker was able to dispose of a 60- to 75-pound fish in about 4 minutes on the average (Figure 16). The trunk of the fish was first slashed around the caudal peduncle anterior to the keel with a heavy keen-edged knife. The blade was then passed along one side of the backbone, ventrally and dorsally. Cutting down through and along the lateral line permitted removal of two loins. The remaining side of th fish was next separated from the backbone and halved. The four loins were then trimmed to fit a standard freezing pan measuring 23" x 13" x $4\frac{3}{4}$". These pans were capable of holding from two to three loins or about 50 pounds of fish each. The small left-over pieces were saved and placed in a separate pan for freezing. Spearfish sections were handled in the same manner as the tun sections. The freezing pans were filled by a crew of three men wh also kept the filleters supplied with fish. Pans when filled were marked as containing either first- or second-grade fillets, although the fish may have been purchased at lower grades. The filled pans are then loaded on push carts and wheeled to the receiving door of the freezing room.

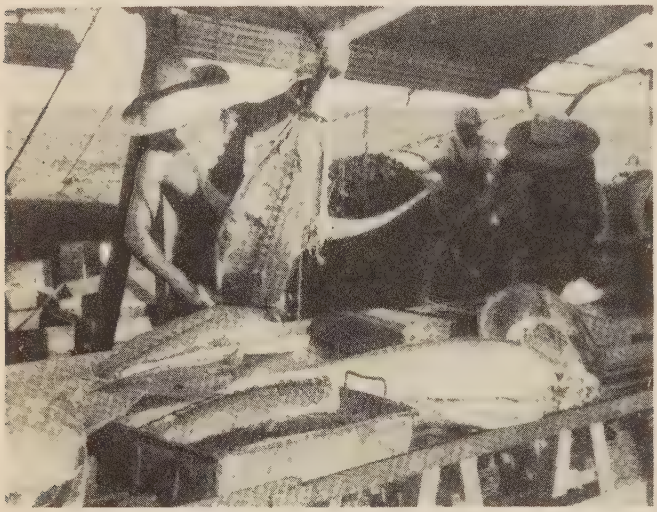


FIGURE 16 - A WORKER FILLETING A YELLOWFIN TUNA.

Often, the filleters were no able to keep up with the flow of fish from the butchers, in which case the fish were piled up on de until they could be handled. The fish were covered on a few occasions with chunks of ice to prevent spoilage, but th procedure was dispensed with when it was determined that the time elapsing before th fish could be filleted was usually not long enough to materially affect the conditi of the fish.

Freezing and Storage of Fish: A single-stage, direct-expansion ammonia system was used to freeze fish aboard the mothership. Four vertical compressors of Japane manufacture were in operation, with a total rated capacity of 250 metric tons. Two compressors, one of 100 tons and one of 50 tons, were used for the freezers. The remaining two compressors formed part of the brine-cooling system which controlled temperatures in the cold-storage holds. Freezer temperatures were brought down to a minimum by the use of -50° C. ammonia; head pressure during normal operation was held at about 215 pounds per square inch.

The below-deck quick-freeze rooms, port and starboard, were not used mainly because of the inconvenience of supplying fish to these two chambers. The freezing o whole fish and fillets was, therefore, conducted in the large freezing chamber on t main deck. This chamber was divided into six freezing compartments connected at ea end by an outer vestibule, or preparation room. Each compartment was provided with two banks of ammonia coils which formed nine shelves on a side. Each shelf was 7 pipes wide and each pipe 2 inches in diameter. Removable galvanized plates were placed on the shelves to increase the area of contact with the fish. The six upper shelves were for freezing pan fish and had a space of seven inches between coils. The three lower shelves were for whole fish and measured 11 inches apart. Each ban of shelves held 120 pans of fish (approximately 50 pounds per pan) and 72 whole fis weighing from 60-70 pounds apiece. The total freezing capacity for all six compartments was about 65 metric tons of fish during a 24-hour period.

Whole and filleted fish were passed through the door of the port vestibule and guided along portable metal grates, installed along the corridor, to a compartment. A similar device was used in the starboard vestibule for removing frozen fish. As the compartment was filled to capacity, grate extensions were removed, the doors closed, and temperatures were lowered. Often, it was not possible to completely fill a compartment in which case, if it were known that more fish would become available in a few hours, the usual practice was to postpone freezing the partially-filled compartment.

Fish were frozen in at least 24 hours at minimum temperatures varying between -20° and -30° C. Temperatures were taken twice daily by means of a thermometer inserted through a hole in the compartment wall above the door adjoining the starboard vestibule. To test whether whole fish were frozen satisfactorily, cores were taken from a sample fish of each lot and examined. A thermometer was inserted into the center of the body after removal of the core, and if the internal temperature read below 0° C., the fish was considered to be thoroughly frozen.

Frozen fillets were given a preliminary fresh-water glaze and removed from pans in the starboard vestibule. The pans were then passed out through the doorway to the main deck for cleaning and filling. The blocks of frozen fish were chuted below for a final glaze and packing into cardboard boxes for storage. Whole fish were individually glazed below and stacked in the main cold-storage holds (Figure 17) rather than in the side wings which were for boxed fillets.

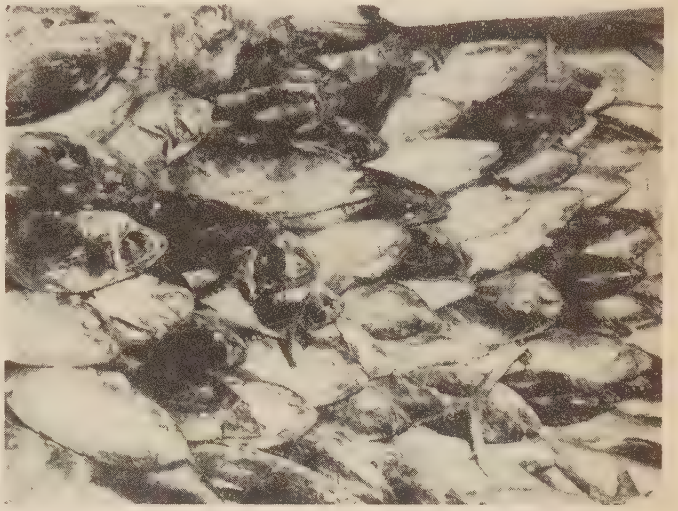


FIGURE 17 - WHOLE YELLOWFIN TUNA FROZEN AND STACKED IN A COLD STORAGE HOLD.

Working Conditions: By United States standards there was considerable room for improvement in efficiency of operations which would have resulted in time and labor savings. It was apparent, however, that the mothership management was not interested in reducing the work through operational planning and the improvement of existing equipment because of the cheap, ample supply of available labor. Simple conveyor systems, for example, would have speeded up deck operations considerably. Lacking these and other labor-saving devices, workers assigned to the handling and processing of fish were subjected to rigorous working conditions and were on call 24 hours a day. These men were seldom able to rest for more than eight hours a day during most of the season and then for only two- or three-hour intervals instead of one continuous period. The ship's crew and those working in the freezer and cold-storage holds were more fortunate in that they worked on a shift basis. In relation to the work performed, all workers were poorly paid. A skilled filleter received as little as $40 per month beside room and board. Production was adversely affected towards he end of the season because of the cumulative effects of hard labor, inadequate rest nd the lack of monetary incentives which visibly affected the workers' efficiency and orale.

Production: According to statistical data provided by the Taiyo Fishing Company, approximately 6,236,000 pounds of final products, not including specialty items, uch as shark fins and livers, were obtained from about 7,683,000 pounds of raw fish onsigned to the mothership during the season. This represents a utilization of over 0 percent of all fish by weight, but as mentioned earlier, many of these fish were lready gutted or gilled when delivered to the mothership. The leading product by

Table 5 - Products Produced Aboard the Mothership[1]

Type of Product	Species	Quantity of Products Produced
		lbs.
Whole, frozen	Tuna	2,375,607
Fillets, frozen ..	Tuna	1,670,798
	Marlin	1,224,918
	Shark	575,275
	Other[2]	172,949
Iced fish	Tuna	113,616
	Marlin	7,268
Livers	Tuna	17,007
	Shark	41,086
Other[3]	-	37,452
Total		6,235,976

1/REPORTED FIGURES.
2/INCLUDES WAHOO AND SMALL TUNA FROZEN WHOLE OR WITH HEADS REMOVED.
3/MOSTLY SHARK FINS.

weight was frozen fillets, but the most valuable was the 2,375,000 pounds of whole frozen fish, almost entirely yellowfin tuna. [3] (The itemized production is presented in Table 5.) Although most of these fish products remained aboard the mothership until her return to Tokyo, some 120,000 pounds of fresh yellowfin tuna, big-eyed tuna and black marlin were picked up and transported back to Japan by a small refrigerated carrier vessel during the middle of August to take advantage of the high prices then prevailing in that market. Catches made at the season's end and brought back to port by the individual catchers were also sold as fresh fish.

ACKNOWLEDGEMENT

This study was made possible by the High Commissioner of the Trust Territory of the Pacific Islands, the Supreme Commander for the Allied Powers, and the Japanese Government. Credit must be extended to the staff of the Fisheries Division, Natural Resources Section, General Headquarters, Supreme Commander for the Allied Powers; and to the Taiyo Fishing Company for making their services and facilities available. The generous assistance of personnel of the Nankai Fisheries Experiment Station and the Japanese Fishery Agency is also acknowledged. Illustrations used in this report were prepared by Miss Alice Hunt, formerly of the Pacific Oceanic Fishery Investigations, U. S. Fish and Wildlife Service, Honolulu, Hawaii.

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[3] UPON RETURN OF THE EXPEDITION TO JAPAN, NEARLY ALL OF THE WHOLE FROZEN FISH WAS SOLD AND EXPORTED TO THE UNITED STATES.

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Reprinted from SCIENCE, June 22, 1951, Vol. 113, No. 2947, pages 717–718.

uccessful Treatment of Ulcer Disease in Brook Trout (*Salvelinus fontinalis*) with Terramycin

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Prior to this report, all chemotherapeutic agents mployed in the treatment of ulcer disease of trout proved unsatisfactory (*1–4*). Investigations on the reatment of this disease were hindered by the lack f adequate information concerning the etiological gent involved. Recently Snieszko *et al.* (*5*) proved *Hemophilus piscium* to be the causative agent of ulcer isease in the Eastern United States, and Flakas (*6*) isolated an unidentified gram-positive bacillus from a imilar disease in Wisconsin. Snieszko *et al.* confirmed he assumption that ulcer disease frequently occurs as mixed infection in conjunction with *Bacterium salmonicida,* the cause of fish furunculosis.

Investigations carried out by Gutsell (*7*) and nieszko *et al.* (*8*) had shown that fish furunculosis ould be treated effectively with certain sulfonamides. urther observations indicated, however, that ulcer isease was apparently refractory to treatment with hese drugs. It therefore seemed likely that the few stances in which ulcer disease had been successfully eated with sulfonamides occurred only in cases of ixed infections.

Some of the newer antibiotics, such as aureomycin) and terramycin (*10*) were employed in an attempt treat infections of ulcer disease. These drugs can administered orally with food without significant ss of their therapeutic properties. This is an important factor, since parenteral administration of rugs to fishes is impractical.

During the summer of 1950, three pilot experients were run with separate lots of fingerling brook out having ulcer disease. Aureomycin hydrochloride as used in form of "Spersoids" (Lederle) at the rate 50 mg/kg trout/day. Terramycin hydrochloride Pfizer) was given at a rate of 75 mg/kg fish/day. he dosages were calculated as the pure substance thout filler. The drugs were mixed with the food, d the fish were fed twice each day; the temperature the water was 13° C; the weight of the trout in rious lots ranged from 6 to 12 g per fish, and the h used in each experiment were of fairly uniform e. Examination had shown that in all outbreaks *piscium* was present in the lesions and tissues of fected trout. In all outbreaks of the disease, some out were also infected with *Bact. salmonicida.*

Ulcer disease usually has an incubation period of 3 weeks, and trout with advanced pathological anges can live for a number of days and sometimes en recover. Infected fish usually have oral ulcerans that hinder feeding (*2*). Therefore, the success of any oral treatment depends to a large degree on the number of fish in the treated lots which still can take the medicated food at the start of the treatment.

Of the two antibiotics used, aureomycin had no therapeutic value. Terramycin was effective, the proportion of surviving trout depending on the rate of mortality at the onset of treatment. In the first experiment, with 6.5% mortality per day at the start, the losses were 80% in the treated fish, and 90–95% in controls after 2 weeks of treatment. In the second experiment, with an initial mortality rate of 1%/day, after 40 days of treatment 25% of the trout died in the treated lot and 97% in controls. In the third experiment, with approximately 3% mortality per day at the start, the total losses after 35 days of treatment were 43% and 47% in the lots receiving terramycin and 85% in the controls.

TABLE 1

MORTALITIES IN FINGERLING BROOK TROUT AFTER TREATMENT WITH TERRAMYCIN

Periods	Terramycin-treated			Controls		
	Replicates		Av (*A* and *B*) % mortality per day*	Replicates		Av (*A* and *B*) % mortality per day*
	A	*B*		*A*	*B*	
August 4–8	7	6	2.3	13	6	3.2
" 9–13	9	12	4.4	8	6	3.1
" 14–18	2	5	1.8	14	8	6.0
" 19–23	2	1	0.8	3	9	4.0
" 24–28	2	2	1.2	6	6	5.8
" 29– September 2	1	0	0.3	1	11	6.4
September 3–7	0	0	0	2	1	3.1
Total number dead	23	26		47	47	
Initial number of trout	55	55		55	55	
Average wt/trout	12.7 g	12.7 g		13.0 g	12.4 g	
Total dead (percentage)	42	47		85	85	

* Calculated from total mortalities during 5-day periods.

The data obtained from the third experiment, which gave about average results, are presented in Table 1.

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TISSUE LEVELS OF VARIOUS SULFONAMIDES IN TROUT

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Abstract

Studies were made on the tissue levels of sulfonamides in trout. The tissue concentrations of sulfamerazine were determined in brook trout given various doses of this drug. It has been found also that there exists a relationship between the rate of feeding, depending on the size of trout, and the tissue concentration of sulfamerazine. The level of sulfamerazine rose much faster and higher in blood and liver than in kidney and muscle. However, after the treatment was discontinued sulfamerazine level in all tissues dropped within 3 days to about 1 milligram percent. From the tested sulfonamides, sulfanilamide was absorbed fastest and produced highest tissue concentration. Sulfamerazine and sulfamethazine gave similar tissue levels, but the tissue concentration rose faster with sulfamerazine. Sulfadiazine and sulfaguanidine reached lower tissue levels. The tissue level of sulfathiazole was less than 1 milligram percent and sulfathalidine and sulfaquinoxaline were not absorbed from the intestine at all.

Introduction

Sulfonamides were first tried for the treatment of trout diseases by Tunison and McCay (1937) and Wolf (1939). These authors tried unsuccessfully to treat ulcer disease by feeding infected trout with food containing large doses of sulfanilamide, the only sulfa drug in general use at that time. When new sulfonamides were introduced, the most promising of them were tested by Gutsell (1946, 1948) who found that sulfamerazine was very effective in the treatment of trout infections caused by *Bacterium salmonicida.* Studies carried out by Wolf (1947) confirmed, in general, the results obtained by Gutsell, and indicated that sulfamerazine therapy was also promising in the treatment of ulcer disease. Gutsell and Snieszko (1949a) determined the optimum dosage of sulfamerazine for the treatment of furunculosis and described (1949b) the effect of this drug on the growth of normal trout of three species. In subsequent studies Snieszko *et al.* (1950) found that in addition to sulfonamides tested by Gutsell (1946), sulfamethazine was about as effective as sulfamerazine in the treatment of furunculosis, and that sulfathiazole was inferior. Recently Slater (1948) used sulfonamides with promising results in the treatment of a salmon disease caused by *Chondrococcus columnaris.*

The first pharmacological investigations were carried out by Litchfield (1939) on a normal spiny dogfish *(Squalus acanthias)*. Flakas

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(1950) determined the blood concentration of sulfonamides in adult brown trout which were therapeutically effective. The rate of penetration of the intestinal wall of trout by various sulfonamides, their distribution in blood and other tissues or organs, as well as the speed with which they were eliminated remained unknown. The objective of the present study was to secure information which would permit a more effective use of sulfonamides for the treatment of some infectious diseases of fishes.

METHODS

Fingerlings or yearlings of brook *(Salvelinus fontinalis),* brown *(Salmo trutta),* or rainbow trout *(Salmo gairdnerii)* were graded, weighed, and distributed into experimental troughs. The temperature of the water was 11° to 13° C. Doses of sulfonamides were expressed in milligrams per 100 grams (milligrams percent) of trout weight per day. The concentrations of sulfonamides in blood or tissues of treated fish were also expressed in milligrams percent. Sulfonamides were mixed with the diet and fish were fed at 8 A.M. and 4 P.M. each day. The quantity of food given to the experimental trout was determined from the feeding charts (Duel *et al.,* 1942) based on requirements per unit of body weight. With small fish it was desirable to determine sulfonamides in entire trout rather than in blood only. In order to eliminate the non-absorbed drugs, the intestinal tract and feces were carefully removed and trout were ground with known volume of distilled water in a Waring blender. For a comparison sulfonamides were determined in a similar way in blood and some of the organs. Usually determinations were made from composite samples of three to five trout. All determinations were made colorimetrically with the method of Bratton and Marshall (1939). Occasionally the total sulfonamides were determined in addition to the free sulfonamides.

RESULTS

First was determined the relationship between the doses and tissue level of sulfonamides. This experiment was carried out three times with brook trout fingerlings of various age groups. In the particular experiment here described, the doses of sulfonamide were 10, 20, and 30 milligrams per 100 grams of fish per day. The trout weighed about 23 grams per fish. Determinations were made in duplicate each day for a 14-day period from fish carried at each level of treatment. Composite samples of three trout were taken at random from separate troughs. In Table 1 and Figure 1 are presented the tissue levels of sulfamerazine from duplicate determinations. The tissue concentrations of sulfamerazine increased during the first 4 days. They were reasonably unform during the next 6 days of treatment and dropped rapidly when sulfamerazine was eliminated from food on the tenth day. The tissue concentrations decreased slightly when one feeding was missed

TABLE 1.—*Levels of free and total sulfamerazine in tissues of normal fingerling brook trout (average weight per trout 23 grams) treated at three different dosages of the drug. Determinations were made on duplicate (A, B) composite samples each consisting of three trout.*

Days after the start of treatment	Dosage rate in milligrams percent											
	10				20				30			
	Sulfamerazine in trout tissues in milligrams percent											
	Free		Total		Free		Total		Free		Total	
	A	B	A	B	A	B	A	B	A	B	A	B
1	2.0	0.1			2.8	2.6			3.8	4.2		
2	2.3	1.5	2.5	1.8	2.3	4.7	3.5	5.3	3.6	5.7	4.0	5.9
3	2.4	2.1	2.9	2.3	1.1	4.5	1.4	6.1	4.5	5.7	5.1	6.1
4[1]	3.2	3.4	4.0	3.8	5.7	7.0	6.1	8.2	8.2	6.1	8.6	6.8
5	2.1	2.4	3.6	2.9	3.1	4.2	4.0	4.9	6.1	3.2	7.0	4.7
6	3.2	3.8			6.9	6.5			9.8	7.9		
7	1.8	4.2	3.3	5.1	6.8	6.9	6.8	7.4	9.2	8.4	9.4	8.6
8[2]	3.6	3.4			6.3	6.3			6.1	7.3		
9	3.2	2.3	3.3	2.6	6.8	6.3	6.8	6.5	7.7	7.7	7.9	7.9
10[3]	1.6	2.0			3.8	4.7			4.7	4.7		
11	0.5	0.9	0.8	0.9	1.6	2.4	1.6	2.6	2.0	1.7	2.0	1.8
12	0.1	0.4			0.8	0.5			0.6	0.6		
13	0.1	0.1	0.2	0.8	0.1	0.4	0.2	0.5	0.2	0.1	0.4	0.4
14	0.4	0.1			0.2	0.2			0.2	0.2		

[1] On the fourth day one afternoon feeding was missed.

[2] After 7 days diets were adjusted to trout weight.

[3] After 9 days treatment with sulfamerazine was discontinued.

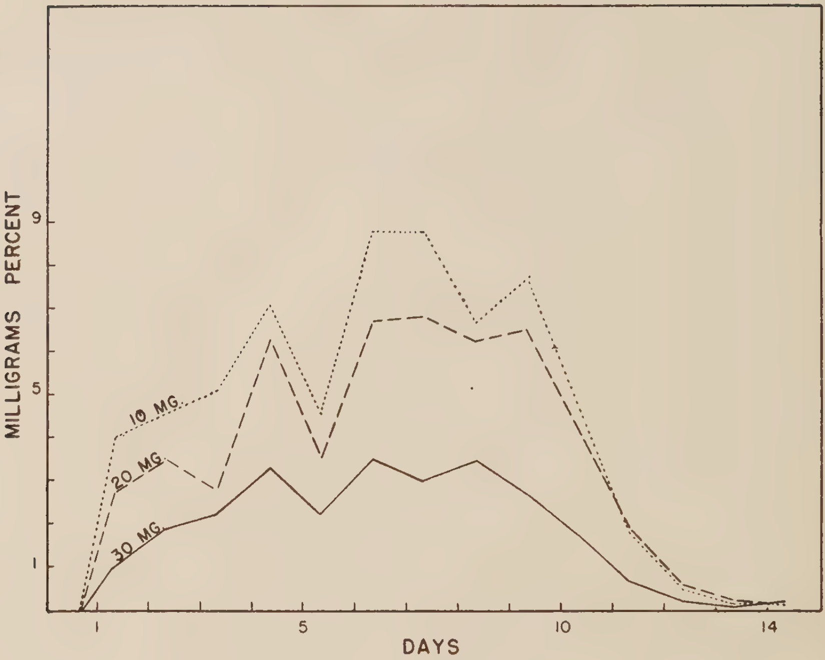

FIGURE 1.—Average levels of free sulfamerazine in tissues of normal brook trout fingerlings treated with three different dosages of the drug. Afternoon feeding missed on the fourth day; diets adjusted after 7 days; and treatment discontinued after 9 days. Dosages are in terms of milligrams per 100 grams of trout per day.

on the fifth day, and also when the dosage was adjusted to the weight of the fish on the eighth day. The experiment indicated that the increase of the dosage rate resulted in increase of the tissue concentrations of sulfamerazine.

Results of this, and of two other experiments, are also presented in Figure 2. They show that the tissue concentrations of sulfamerazine given at the same doses were higher in older fish which were fed at a lower rate (Duel *et al.,* 1942). This relative increase of the level of sulfamerazine in older trout is due to the reduced quantity of food.[1]

For rational treatment of the infectious diseases of fishes with sulfonamides, it was important to establish the therapeutically effective concentration of the drug in the blood, and to maintain it at this level during the whole period of treatment. To test the value of the high initial dose in fishes, brook trout fingerlings, average weight 33 grams, were divided in three lots and six troughs. All trout were treated at

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[1] **Results of this and other additional experiments will be published later.**

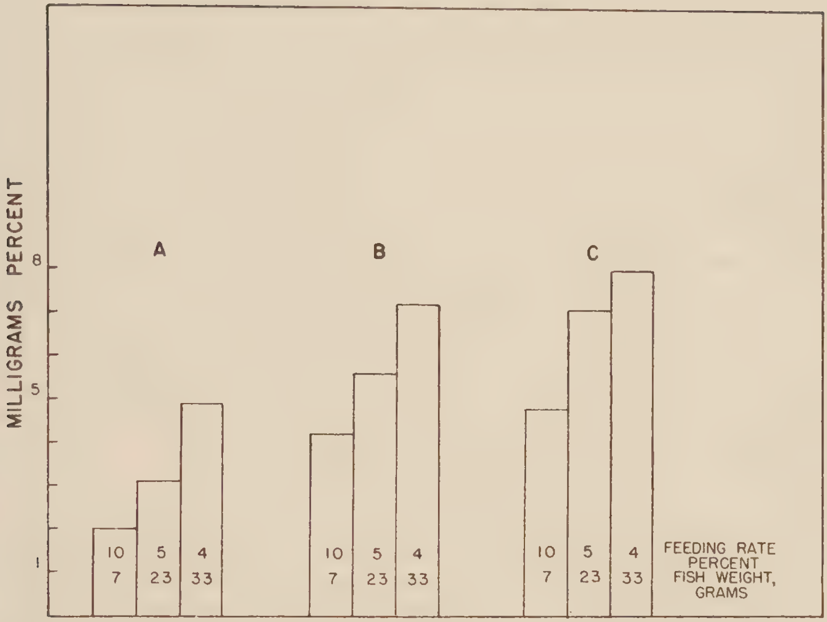

Figure 2.—The average tissue levels of free sulfamerazine in three lots of brook trout fingerlings. Each lot was of different age and size, and was tested at different times. Each lot was fed at a different rate (Duel *et al.* 1942). Dosages are, A 10, B 20, and C 30 milligrams per 100 grams of fish per day.

first with sulfamerazine at the relatively high rate of 30 milligrams per 100 grams of fish per day. The tissue concentration rose slowly until it started to level off on the fourth day at 9 milligrams percent. From the seventh day, fish in each pair of troughs received sulfamerazine at different rates of 10, 20, and 30 milligrams percent. In trout receiving 10 and 20 milligrams daily doses, the tissue levels dropped considerably within several days. In these trout it was only slightly higher than in trout used in other experiments in which fishes were treated with identical dosages but without the benefit of the high initial doses. This slight increase was due to the larger size of fish used in this test which received food at a lower rate (Duel *et al.*, 1942). The advantage of high initial dosage in trout was the somewhat shortened time with which the higher tissue level was reached. The subsequent lower doses did not permit the maintenance of the high tissue concentration obtained by the high initial dosage.

The concentrations of sulfonamides in man and larger domestic animals are determined from blood samples. In small trout this is not practical because the quantity of blood which can be obtained is usually inadequate for such purposes. Therefore in order to be able to com-

TABLE 2.—*Levels of free sulfamerazine expressed as milligrams percent in various tissues and feces of yearling brook trout (average weight 83 grams) which received the drug at the rate of 20 milligrams per 100 grams of fish per day. Determinations were made with composite samples, each of six trout.*

Days after the start of treatment	Tissue or organ				
	Muscle	Blood	Liver	Kidney	Feces
2	3.4	7.4	7.0	5.1	....
3	4.2	7.2	10.0	10.0	300
8	7.9	14.2	15.6	11.4	750
9	8.6	25.0	22.0	12.4	500
10	7.2	13.0	13.6	11.1	245
11[1]	5.7	10.6	11.4	7.9	....
14	5.5	8.0	8.0	7.2	340
15[2]	5.3	9.0	9.0	7.2	115
16	2.0	2.6	3.6	2.1	40
17	0.6	0.9	1.6	0.9	12
18	0.5	0.8	1.2	0.5	5.5

[1] Quantity of drug and diet was adjusted to the weight of trout.
[2] Treatment with sulfamerazine was ended.

pare the relative concentrations of sulfonamides in the blood and some organs of trout with that of the entire fishes, determinations were made with blood, kidney, liver, and muscle tissues of yearling brook trout. All tests were run with composite samples consisting of blood and tissues pooled from six trout for each determination. As it is evident from Table 2 and Figure 3, the concentration of sulfamerazine reached highest levels in blood and liver. In the kidney tissue it was somewhat higher than in the muscles. It is interesting to note that the concentration of sulfamerazine increased rapidly up to the ninth day and then dropped sharply although the dosage was continued at the same rate. The concentration of sulfamerazine in the contents of the gut during the treatment was very high (Table 2). Feeding a diet containing sulfamerazine was discontinued on the 14th day. Consequently, the concentration of sulfamerazine decreased uniformly in blood and other tissues. When on the 17th day the concentration of the drug in all tissues was only 1 to 2 milligrams percent, in the intestinal contents it was still about 12 milligrams percent. This experiment was repeated at another time with brown trout yearlings and the results duplicated the data here presented.

Finally, the tissue concentrations of eight different sulfonamides which have been tried in the treatment of furunculosis or other fish infections were determined. All sulfonamides were given to brook trout fingerlings weighing on the average 2.5 or 4.0 grams per trout. All determinations were made with composite samples of five trout. Results are presented in Table 3 and Figure 4. Sulfanilamide was absorbed very rapidly and reached the tissue concentration of 8 to 9 milligrams percent. The concentration started to drop from the ninth day regardless of continued treatment. This sudden drop of tissue concentration

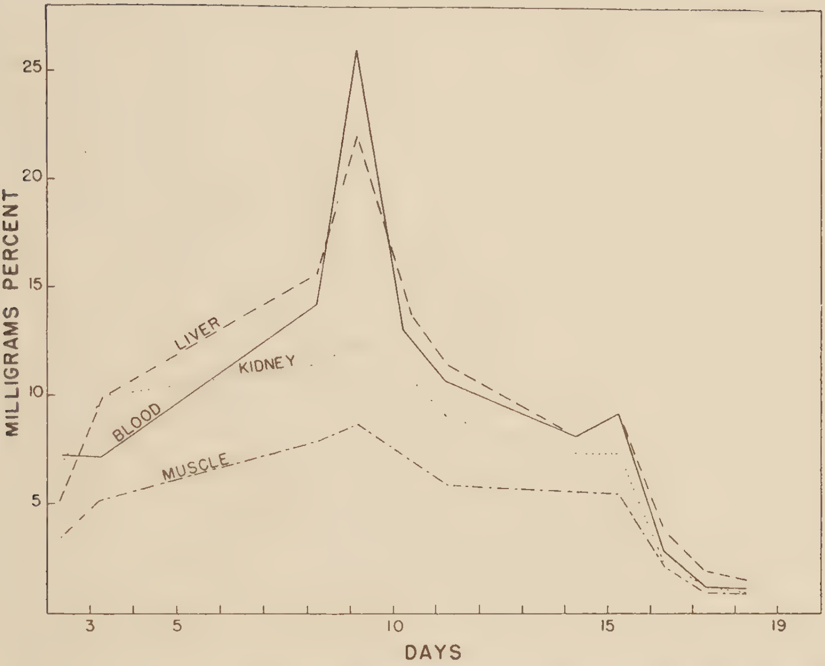

Figure 3.—Levels of free sulfamerazine in various tissues of brook trout yearlings which received the drug at the rate of 20 milligrams per 100 grams of fish per day. (M) muscle; (B) blood; (L) liver; (K) kidney. Concentration in feces too high to be shown.

of sulfanilamide was due to some undetermined cause. The tissue concentration of sulfamerazine reached a somewhat lower level than that of sulfamethazine but the absorption of the former was faster. This observation accounts for the results of Snieszko *et al.* (1950), who found that the therapeutic action of sulfamethazine was somewhat slower than that of sulfamerazine. It is interesting to note that sulfathiazole was only slightly absorbed. Nevertheless, this drug was moderately effective in the treatment of furunculosis (Gutsell, 1948; Snieszko *et al.*, 1950). Sulfathalidine and sulfaquinoxaline were not absorbed from the intestinal tract. The latter was tried in the treatment of furunculosis and was found ineffective.

Discussion and Recommendation for Treatment

The development of chemotherapy for any infectious disease is not a purely empirical process based on testing innumerable drugs. The pharmacological basis for chemotherapy depends on the understanding of the action, distribution, and excretion of drugs in the body. There is

TABLE 3.—*Tissue levels of various sulfonamides in fingerling brook trout of average weight of 2.5 and 4.0 grams. Dosage 20 milligrams of sulfonamide per 100 grams of trout per day. Determinations were made on duplicate (A, B) composite samples of five trout each.*

Days after the start of treatment	Sulfamerazine[1]		Sulfaguanidine[1]		Sulfadiazine[1]		Sulfamethazine[1]		Sulfanilamide[2]		Sulfathiazole[2]	
	A	B	A	B	A	B	A	B	A	B	A	B
1	4.2	4.2	1.6	1.1	3.7	3.7	2.9	1.9	2.1	4.0	0.0	0.0
2	5.3	1.6	0.8	1.3	3.3	3.3	2.9	3.2	9.0	7.8	0.6	0.7
3	4.2	5.5	0.6	0.5	2.1	1.6	3.2	3.7	8.0	8.2	0.8	0.8
4	5.3	7.0	1.2	1.1	2.5	2.4	3.5	2.7	3.6	2.4	0.3	0.2
7	5.9	5.5	0.8	0.8	2.2	2.4	5.4	4.0	7.8	9.0	0.1	0.1
9	5.5	5.3	3.1	3.0	3.0	2.8	8.0	6.0	9.6	9.0	0.4	0.5
11	5.9	6.8	2.0	1.9	3.7	3.0	7.3	8.3	3.6	5.2	0.8	0.2
13	5.5	5.5	2.1	2.1	3.0	3.6	6.4	7.7	.....	.....	.....	.....
14	5.7	6.1	2.1	1.9	3.0	2.7	5.7	5.5	.....	.....	.....	.....
15	3.8	3.1	1.3	1.3	3.3	2.2	3.8	3.2	4.7	3.3	0.2	0.1
16	1.1	0.8	0.2	0.1	0.6	0.5	0.3	0.0	2.7	3.7	0.2	0.0
17	.....	.....	.....	.....	.....	.....	.....	.....	1.0	1.4	0.0	0.0
18	.....	.....	.....	.....	.....	.....	.....	.....	0.4	0.2	0.0	0.0

Sulfathalidine and sulfaquinoxaline were not absorbed from the intestinal tract.

[1] Treatment discontinued after 14 days.

[2] Treatment discontinued after 15 days.

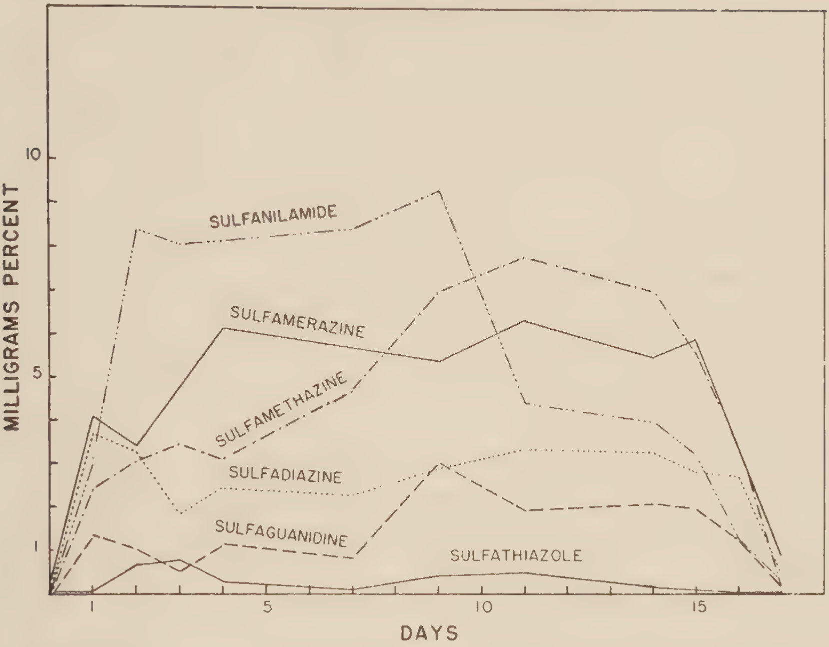

FIGURE 4.—Average tissue levels of various sulfonamides given at a rate of 20 milligrams per 100 grams of fingerling brook trout per day. There was no absorption with sulfathalidine and sulfaquinoxaline.

no certainty that a drug which is toxic to the pathogen *in vitro* will be similarly active *in vivo.* The bactericidal action *in vivo* is dependent not only on the toxicity of a drug for the pathogen, but also on the rate of absorption and excretion of drug and its power of penetrating tissues (Work and Work, 1948; Northey, 1948).

The first pharmacological study on sulfonamides in fishes was carried out by Litchfield (1939). He introduced sulfanilamide to dogfish enterally and parenterally and found that the toxic effect of the drug became evident when the blood concentration reached 5 milligrams percent. The enteral absorption *per cloaca* was very rapid, but *per os* was slower, probably as a result of the gradual and variable emptying of the stomach. This observation is in accord with those here reported, which show that the highest tissue concentration in trout was reached only after several days of treatment.

The optimum therapeutic dosage of sulfamerazine for treatment of furunculosis in brook trout according to Gutsell and Snieszko (1949) was 8 grams of the drug per 100 pounds, which is equal to 17.6 milligrams per 100 grams of fish per day. Satisfactory therapeutic results

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BIOLOGICAL EFFECTS OF DDT APPLICATIONS ON TIDAL SALT MARSHES

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Consequent to the increased use of DDT and other insecticides for the control of salt-marsh mosquitoes, there has been a growing concern over possible hazards to fish and wildlife. In an effort to evaluate properly any harmful features of such programs, and to seek means for minimizing any dangers to beneficial life, the Fish and Wildlife Service, in cooperation with other agencies, initiated an investigation in 1949. This report summarizes the results obtained during the first two years (1949–1950) of such a study.

Concerning salt-marsh mosquito control with DDT, little is known of the direct or indirect damage to fish, marsh birds and waterfowl, and to such commercially important invertebrates as blue crabs, clams, oysters, and bait shrimp. The present study has aimed to determine the extent of damage sustained by wildlife with sprayings comparable to those applied for control of mosquito larvae. However, due to the small amount of population work on many of the organisms encountered, a considerable portion of the investigation necessarily was directed toward the development of suitable study methods.

The Area and Methods

Studies were conducted on the salt marshes of Brigantine National Wildlife Refuge, Oceanville, New Jersey. In addition to the Fish and Wildlife Service, several federal and state agencies participated. The Bureau of Entomology and Plant Quarantine of the U. S. Department of Agriculture furnished insecticide and the plane; the New Jersey Agricultural Experiment Station studied effects of the aerial applications upon insect pests of the area and personnel of the New Jersey Fish and Game Division assisted materially in several phases of the project.

In 1949, four study areas were established and treated by plane at rates of 1.6, 0.8, 0.4 and 0.2 pounds of DDT per acre respectively. Two applications were made, the first between August 17 and 19 mostly at high tide and the second on September 15 and 16 at low tide. Each plot included 100 acres except for the 1.6 area which was 50 acres. Realignment of the plot boundaries before the second treatment resulted in some portions of each of the areas being treated only once and other parts twice. For comparison, studies were also made throughout the summer on the fluctuations of animal populations in suitable unsprayed check areas.

Since the 1949 studies clearly established the consequences to aquatic life of the 1.6 pounds per acre application, this dosage was omitted from the 1950 program. However, in this second year of study the former 0.8 pound per acre plot received an application of 1.0 pound per acre, and the 0.4 and 0.2 areas of 1949 were treated in 1950 at rates of 0.5 and 0.25 pound per acre respectively.[1] Three sprayings were made on each area at low tide on July 6, August 4 and September 3. Although the 1.6 area of 1949 was not re-treated in 1950, follow-up studies were conducted to determine the presence of any continued effects.

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[1] Hereafter these areas or dosages are referred to as the 1.6, 1.0, 0.8, 0.5, 0.4, 0.25, and 0.2 areas or dosages.

During the first year the spray used was Shell ACX-331 containing 10.75 per cent DDT in light fuel oil with an auxiliary solvent. Different dosages were obtained by varying the volume of spray applied. With this procedure, higher dosage plots received more oil solvent than the lower dosage areas. Since oil is toxic to certain forms of life, greater or lesser kills might be expected according to the amount applied. This fact recommended a change in the 1950 program, and during the second year, 20, 10 and 5 per cent oil sprays were made up for the 1.0, 0.5 and 0.25 areas respectively. Consequently, equal quantities of spray per acre were applied on each of the areas, the amount of DDT being the only variable.

Pre- and post-spray studies of populations and of animal behavior in sprayed and untreated areas were the chief investigative methods employed, and techniques used are described at appropriate places in the text. Since the majority of invertebrates are more readily affected by DDT than vertebrates, it was felt that spraying effects on the latter would be largely indirect and evidenced primarily through disturbances to invertebrate populations. Consequently, invertebrates received major emphasis in this study. Many of these serve directly or indirectly as a source of food for vertebrates, and a few, such as the blue crab, are of commercial value.

OBSERVATIONS ON BIRDS

Gulls.—Greatly increased numbers of gulls, mostly laughing gulls, *Larus atricilla,* were usually seen at low tide on the day following spraying. These increases were noted in areas where considerable mortality to fish, crabs and shrimp had occurred. The actions and cries of feeding gulls undoubtedly attracted birds from considerable distances as up to 500 were sometimes seen in an area. These concentrations largely disappeared by the second day following treatment. Thereafter, in some cases, a below-average number of gulls were present in the sprayed areas. Strip counts on the 1.6 and 0.8 plots before and after spraying in August showed an 85 per cent decrease in numb of gulls following treatment. No harm effects to these birds could be discern even though they consumed large quan ties of DDT-contaminated animals. Usu numbers were again seen in the are within several weeks following sprayi

Clapper Rail.—Though it was diffic to observe feeding habits of clapper ra *Rallus longirostris,* it was evident that th consumed many DDT-affected fidd crabs. This was indicated by the increas number of large claws of the male cra following spraying. These are commo discarded by rails when eating fiddle Surveys of the plots after treatment vealed no dead birds in 1949, but in 19 a young rail about one week old was fou dying in the 0.25 area, 40 hours after t August 4 spraying. Upon death, tiss from this specimen were analyzed a found to contain DDT in quantities s ficient to suggest acute poisoning. Si this bird was recovered on the low dosage plot, it seems reasonable to assu that other deaths may have occurred areas of heavy dosage.

Following the July, 1950 applicati observations were made on a total of nests located in treated plots, five of wh were in the 1.0 area. All nests produ successful hatches indicating no appar effects to parents or young. Several ra collected at various times after treatm had well-filled gizzards, indicating t there was no shortage of food.

Herons.—Increased numbers of her and egrets entered some of the study pl for a few days after spraying. None w observed eating dead fish, nor were th any indications of mortality to these bir

Swallows.—Tree swallows, *Iridopro bicolor,* while very common before t August, 1949 spraying in the 1.6 and areas, decreased greatly thereafter. St counts showed declines in these areas 52 and 41 per cent respectively. Me while, increased numbers of birds w observed feeding in nearby untreated are However, this was only a tempor change as the usual numbers were ag seen over the sprayed plot before the n treatment. Swallows were less numerous before spraying in the lower dosage areas and any changes thereafter were not noted.

Song Birds.—The effects of DDT on small resident song birds including the long-billed marsh wren, *Telmatodytes palustris*, sharp-tailed sparrow, *Ammospiza caudacuta*, and seaside sparrow, *A. maritima*, were determined by strip counts in the higher dosage areas. An average of 26 birds in the 1.6 area, and 29 birds in the 0.8 area were present before spraying. Afterwards averages of 26 and 32 birds respectively were seen, indicating no significant changes. No observable harm resulted to several nestlings and young birds just out of the nest in the high dosage areas. Collection and examination of both young and adult specimens five days after spraying showed that all had well-filled gizzards.

EFFECTS ON FISHES

Investigations were made of DDT effect upon the common fishes of the salt marsh, principally killifish. Two species were especially typical: *Fundulus heteroclitus*, found abundantly in all aquatic habitats, and *Cyprinodon variegatus*, which occurred largely in ponds.

General observations indicated that killifish were readily affected by DDT spray, the results being largely in accord with the dosages applied. At rates of 0.8 pound per acre and above, poisoning symptoms were observed within four hours after low-tide treatments, and at lower dosages within nine hours after spraying. The maximum number of dead and affected fish were usually seen 18 to 24 hours following spray application. In the low dosage areas, all visible effects of spraying had disappeared by the second to fourth day after treatment while in the 1.6 and 0.8 areas dead fish were seen until the fourth or fifth day.

Heavy losses of fish occurred as a result of the 1.6 dosage spraying. Small *Fundulus* less than 1½ inches long made up the majority of the kill in the creeks and ditches but there were a number of larger individuals up to 3 inches in length. Mortality was not complete and many fish were seen during succeeding tides. In ponds the kill was greater, being nearly complete in the shallow bodies. This difference was probably associated with the greater concentration of spray in the shallow water areas and the greater possibility of contact by fish.

Lower mortalities occurred in the 0.8 area and the number of dead and affected fish was only about half of that present in the 1.6 area. Even less mortality occurred in the 1.0 area in 1950 and here the losses were only a little greater than those observed in low-dosage areas. Although a number of small fish were affected within four to five hours following the 1.0 spraying, most of them recovered. The difference between the two years' spraying appears to be due to the greater volume of oil used in the 1949 operations. The effects of spraying at the lower dosages were much reduced and were confined to the smaller sized fish in the shallow ponds and ditches. A number of affected fish were noted in the areas but only a few succumbed. No mortality or evident harm to fish was observed in the check areas before or after sprayings.

Observations of effects of the various sprayings were confirmed, in a general way, by cage experiments although results from the latter were clouded by mortalities from handling and by probable weakening of fish through confinement. However, handling mortality was largely eliminated during the second and third treatments in 1950.

These experiments showed about a 70 per cent loss of fish in both creek and pond cages at the 1.0 pound per acre application. In the 0.5 and 0.25 areas, small fish (under 2 inches in length) suffered about 50 per cent reductions in both creek and pond habitats. Losses to larger fish (over 2 inches in length) in the lower dosage areas were somewhat less. Creeks showed a 40 per cent mortality in the 0.5 area and half of that in the 0.25 area. In ponds, the greatest losses to large fish occurred in the 0.25 area where a 45 per cent mortality was observed as compared to a 20 per cent loss in the 0.5 area. *Cyprinodon* killifish proved to be more resistant to DDT spray than *Fundulus* in the pond tests.

Cage studies were also made to determine if fish in the main drainage creeks outside each of the treated areas were affected by DDT spraying. No mortalities occurred among large or small fish placed at an average distance of about 1800 feet beyond the far ends of the plots.

A more natural means of confinement used in the 0.4 and 0.2 areas consisted in screening-off sections of creeks which retained considerable water at low tide. Dead and live fish subsequently recovered indicated a mortality of 86 per cent in the 0.4 area following spraying. However, almost no mortality was observed in a similar experiment in the 0.2 area.

Studies on Invertebrates

Insects.—Net sweepings along established courses, before and after DDT sprayings, gave indices of the populations of various kinds of insects in the marsh and also denoted the comparative decline in numbers following treatments. Of the insects present on the salt marsh, leafhoppers (Homoptera) and flies (Diptera) were found to be most abundant in numbers of individuals.

Severe reductions in populations resulted from DDT spraying. Declines following a single spraying ranged from about 15 to over 80 per cent, the losses being roughly proportional to the dosage applied. True bugs (Hemiptera) were almost completely eliminated. Leafhoppers and flies were more resistant, especially the former. Survival of various species proved to be distinctly greater in tall grass than in short grass, probably due to the greater screening effect of the higher vegetation.

The duration of spraying effects on insects was found to depend upon the dosage applied and the time of the year. Areas treated with high dosages (0.8 and above) in mid-August showed continuing declines in populations through September followed by complete recovery the next summer. However, the residual effects from treatments in early July disappeared largely in less than a month although populations had still not attained pre-spray levels by the end of the summer. On the other hand, sprayings at lower dosages (0.5 and below) were followed by complete population recovery within seven weeks.

Repeated treatments strongly curbed increases in insect numbers. Populations in the 0.5 and 0.25 areas were reduced about 90 per cent by the end of the summer as compared to pre-spray populations while during the same period the check area populations rose approximately 80 per cent.

Blue crabs (Callinectes sapidus).—These animals proved to be very susceptible to DDT applications and in some cases suffered severe losses. In the watercourses these reductions as well as other effects of DDT spraying were demonstrated by means of general observations, by trapping crabs in commercial type crab pots and by periodic confinement and counting of crabs in screened sections of creeks and ditches.

Screened channel sections were used to help appraise crab mortality in conjunction with the second 1949 spraying and all the 1950 treatments. Screen barriers extending above the high tide level were erected within the channels of creeks and ditches of each area and enclosed portions of individual creeks or of creek systems ranging up to 4300 feet in length. The screens were adjustable and could be raised and lowered to permit the passage of crabs or to enable confining them at low tide for counting purposes. All enclosed creek channels contained sufficient water at low tide to maintain crabs. Dead individuals were removed as they were found.

Information on spraying effects on blue crabs was also obtained by means of crab pot catches taken at weekly intervals throughout the 1950 season. Resulting data, although not as accurate as those obtained from the enclosed creek systems tend to confirm the findings obtained by other methods.

General observations together with screened-channel studies and crab-pot catches showed that the greatest losses among crabs occurred at the higher rates of application (0.8 pound per acre and above). Low-tide sprayings with these dosages produced typical symptoms of DDT poisoning within two hours after treatment. However, the greatest effect from spraying at these and at lower dosages did not occur until 18–24 hours later. Surveys at this time in creeks and ditches of the 1.6 area revealed a very heavy mortality of crabs that had been present at the time of spraying. The few live crabs that were seen showed effects of DDT poisoning. Probably some affected crabs had left during preceding ebb tides but the numbers of dead crabs that were found indicated that the kill within the area had been nearly complete. Results in the 1.0 and 0.8 areas were similar although mortality was not as sudden and about one-third of the crabs present 24 hours after spraying were still alive. Crabs entering these areas during subsequent incoming tides suffered mortalities for a period of about two weeks.

Repopulation was slow and was approximately half completed in four weeks. Complete recovery in the 1.6 area treated in both August and September did not occur until the middle of the succeeding summer. The 0.8 plot of 1949 received a single 1.0 pound treatment again in July, 1950 and at the end of this second season its average population was approximately one-fifth as great as the population prior to treatment the previous year. Seven weeks were required for the population to rebuild to the 1950 pre-spray level.

Effects of treatments at the lower dosages were more variable. General observations during the first season indicated light mortality in the 0.2 area and only a moderate kill in the 0.4 area. However, confinement of crab populations in the creek channels of these areas revealed kills of 60 per cent in the 0.2 and 90 per cent in the 0.4 area during periods of one and two weeks respectively.

Channel enclosures operative during the period of a single tide showed losses of over 89 per cent in the 0.5 area and from 20 to over 40 per cent in the 0.25 area. DDT mortality in both areas was of about seven days' duration. The number of dead crabs recovered in the 0.5 area following spraying did not account for the total number missing and indicates that either crabs were dying outside the creek system or that they did not enter in the usual numbers. Within a day or so after the termination of mortality, crabs were as plentiful in the 0.25 area as before spraying. In the 0.5 area this process required two additional weeks.

Pond habitats showed greater losses than creeks and ditches. Nearly complete mortality was observed following single treatments of ponds at the high dosage rates. After the third spraying a survey of 19 ponds in the 0.5 area revealed no living crabs while at the same time only two could be found in 16 ponds in the 0.25 area. As in the case of fish, more severe kills in these low dosage areas were noted in shallow ponds than in deep ponds. The lack of flushing action, except by spring tides, undoubtedly accounted for the greater kills observed in ponds as compared to creeks and ditches. Tides, of course, also regulate the time and frequency with which crabs from outlying areas can enter and restock these depleted ponds.

Investigations during the 1950 season on an unsprayed plot indicated that the crab population of that area increased until the latter part of July after which a fairly stable level was maintained until the middle of September. A low and uniform natural mortality occurred throughout the season. This natural mortality rate gave a basis for comparison with losses on the sprayed areas.

Fiddler Crabs.—The evaluation of DDT mortality to salt-marsh fiddler crabs, *Uca pugnax,* proved difficult due to their burrowing habits. Losses occurred and in some cases were very great. In general, however, they were proportionately less than those suffered by blue crabs.

Besides general observations, a number of techniques were employed to measure fiddler crab populations and mortality.

The use of square frames of screen or metal, measuring 1 to 2 feet on a side and 18 inches high, proved of most value. These were placed in previously dug holes in banks from which all crabs had been removed. They extended at least 12 inches below the surface, the greatest depth at which fiddler burrows were encountered. After the mud was replaced, a known number of crabs were introduced and a cover of hardware cloth or screening placed on top to prevent escape of fiddlers and depredation by birds. Counts of live and dead crabs dug after spraying indicated mortalities in the different dosage areas.

Another procedure involved the use of a foot-square frame having sides 6 inches high. After this frame was forced a short distance into the ground in selected localities, collections and counts were made of all the small crabs and other invertebrates within its confines. Sampling by this means indicated considerably less mortality to small fiddlers in grassy, more protected areas than in open banks.

Kills in areas treated at dosages of 0.8 pound per acre and above were more immediate than in those treated at lower rates. Many dead and dying crabs were noted in the former areas on the day following spraying, but peak mortalities were noted on the second day. Thereafter, deaths declined and mortality largely ceased 10 days after spraying. The casualties in bare flats were proportionately greater than those occurring on creek and ditch banks where the drainage was better.

In the lower dosage plots, losses were usually first noted on the second day after treatment and were greatest on this or the third day. By the fifth to seventh day after spraying no further mortality from DDT could be observed.

Counts of crabs dug out a week after spraying indicated a total reduction of 42 per cent in the 0.5 area and 24 per cent in the 0.25 area of which 22 and 11 per cent respectively were due to known mortality. At the same time the check area suffered an eight per cent reduction and one per cent known mortality. Although this method was not used in the higher dosage areas, a similar technique there revealed mortalities up to 50 per cent.

The studies also indicated that losses among small-sized fiddlers less than 0.5 inch wide were greater than those among larger individuals. Mortalities ranged 10–15 per cent higher in the 0.25 area and were complete or nearly complete in the 1.6 plot.

Many affected, sluggish crabs were seen after sprayings. Some of these probably survived but many were eaten by birds as evidenced by the greatly increased numbers of large claws of the males. Comparisons were made of the average numbers of claws found per day along the banks of the enclosed creek and ditch systems in each area. These indicated that mortality from spraying was from 3.5 to 34 times as great as that found either before treatment or after DDT mortality had ceased. The greatest increase (34 times) was observed at the higher dosages.

Some dead crabs were noted also at distances of over 200 yards beyond the boundaries of the sprayed plots. Such observations indicate that as a result of spray drift and the transport of DDT by tidal creeks and ditches, the hazards of treatment are not confined to the limits of the sprayed plots.

Other Invertebrates.—Soil-surface sampling indicated no observable effects to mussels (*Volsella demissa*) from DDT applications. A slight seasonal increase in numbers was noted in these studies. Groups of mussels were also located and counted at intervals throughout the summer. No mortality was observed after the August, 1950 spraying. Some deaths occurred in September but the same was also noted in the check area.

Saltmarsh snails (*Melampus lineatus*) were very common and likewise did not appear to be affected by DDT treatments. Soil-surface sampling showed a general increase in the total numbers and in the total volume of snails in all plots following spraying. In similar manner, the average snail size increased through the summer in all except the 1.6 plot where increased numbers of small individuals reduced the size average slightly. Although counts in the 1.6 area in 1950 were somewhat below the numbers recorded the previous year, a similar situation prevailed in the check area.

A number of dead and sluggish clam worms (*Nereis* sp.) were noted on the soft mud bottoms of shallow ponds and drained creeks within a day following spraying. Although such effects were observed in all the study plots, they were most noticeable in the high-dosage areas. Mortality appeared to extend for several days. No quantitative counts were made.

Bait shrimp (*Palaemonetes pugio*) proved very susceptible to DDT poisoning. Considerable numbers of dead individuals were noted along creek and ditch banks within 12 hours after spraying. These observations were confirmed by effects on shrimp confined in cages as well as by seine hauls made under standard conditions. Mortalities were severe in the 0.5 area and light to heavy in the 0.25 area. However, some live shrimp were always seen after spraying suggesting either that not all were affected or that enough DDT had been washed out to make these waters tolerable. Mortality apparently ceased by the third day following application and more live shrimp were seen thereafter. Two weeks after spraying, they were as plentiful as before treatment. Undoubtedly reinvasion accounted in large part for this repopulation.

Soil-surface sampling revealed clear-cut evidence of the high susceptibility of marsh fleas *(Orchestia grillus)* to DDT spray. Following the August, 1949 treatment, no live individuals were seen in any of the areas. Second-year observations in the 1.6 plot showed that these amphipods were still absent one full year following spraying. Consequently, in addition to being highly susceptible, it appears that this form is slow to reestablish itself on treated areas. Live marsh fleas were noted after the August, 1950 treatment in a high part of the 0.25 area under a dense mat of dead grass. This indicates that they can survive if, in addition to protective cover, they are above the normal tide level of DDT-bearing waters. During the two-year period, populations in the check area maintained themselves or increased.

Salt-marsh sowbugs (*Philoscia* sp.) showed DDT susceptibility similar to that of marsh fleas. However, several live individuals noted in soil samples after spraying suggest that they may be more resistant.

Contrary to reports of high resistance by some spiders to DDT, the present investigations indicate these salt-marsh arachnids suffered heavy losses. Within 24 hours of spraying, dead and dying individuals of the commonly distributed wolf spider were noted throughout the treated areas. However, conspicuous numbers of dead spiders were apparent for only two days after spraying.

Results of soil sampling indicated 50 to 90 per cent reductions in the numbers of ground-inhabiting spiders after spraying. The casualties were greatest in areas of heaviest application. Meanwhile check-area populations remained the same. There was no recovery of spiders in sprayed plots by the end of the first summer but studies in August, 1950, in the 1.6 plot (not treated second year) showed that populations were only a little below the original pre-spray levels.

The effects upon web-building spiders were much the same. Webs inhabited by spiders before spraying were deserted afterwards although similar studies in check areas revealed practically no reduction in number of active webs. Populations sprayed in midsummer did not show any degree of recovery in net-sweeping counts until early the following summer but the effects from treatments in early summer persisted for less than a month.

In contrast to the decline of spiders, there were general increases in red mite populations following spraying. This was revealed by soil samples and by net sweepings. The largest gains were observed in the 1.6 area. Meanwhile check area populations remained nearly stable. Similar large increases of red mites following DDT spraying have been noted elsewhere.

Summary

Experimental studies were conducted on a New Jersey salt marsh during the summers of 1949 and 1950 to determine the hazards to wildlife from mosquito control involving use of DDT. Four plots were established and treated by plane at dosages ranging from 0.2 to 1.6 pounds of DDT per acre. Each plot was sprayed two or three times each year at approximately monthly intervals, except the 1.6 area, treated only in 1949. Studies were conducted before and after each treatment to determine the effects of spraying upon populations of the principal wildlife species and upon invertebrates which serve as food for wildlife.

Birds apparently suffered little direct harm although a one-week old clapper rail died from acute DDT poisoning on the 0.25 area. Local movements of swallows and gulls were noted in response to depletion or increased availability of food but these were only temporary and no mortality was evident. No changes resulting from sprayings were observed in numbers of song birds after the breeding season and they, along with rails, appeared to find sufficient food.

Killifish proved susceptible to DDT spray with heavy kills occurring at the 1.6 and 0.8 pounds per acre applications. Visible effects of spraying continued up to five days after treatment. Only light kills were observed at dosages below 0.5 pound per acre. However, cage experiments at these same levels indicated considerably higher mortalities to confined fish. Ponds generally sustained greater losses than did creeks and ditches. Repopulation of waterways by fish from outside the areas occurred rapidly except in the case of ponds not affected by daily tide flows.

DDT applications were very toxic to blue crabs. Dosages of 0.8 pound per acre and above resulted in complete or nearly complete kills of the crabs. Such areas remained toxic for two weeks. Lower dosage levels showed population reductions ranging from 20 to 80 per cent over a seven-day period following spraying. Time required for repopulation varied from a few days (0.25 area) to 2 weeks (0.5 area) after mortality ceased. As with fish, crab losses in ponds were higher than those in creeks and ditches.

In common with other crustaceans, fiddler crabs were readily affected by DDT treatments. Losses of 10 to 20 per cent occurred in the 0.25 area and 20 to 40 per cent in the 0.5 area. Somewhat greater mortality resulted at higher dosages. Small fiddlers less than 0.5 inch wide were most susceptible.

Other small invertebrates were variously affected. Amphipods, sowbugs and bait shrimp incurred very heavy losses while insects, spiders and worms were somewhat more resistant. Little or no apparent harm resulted to red mites, snails and mussels.

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Bottom Fauna and Temperature Conditions in Relation to Trout Management in St. Mary's River, Augusta County, Virginia[1]

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St. Mary's River is one of the better trout streams in the George Washington National Forest and, as a consequence, has been the subject of several investigations (Surber, 1940). It arises from small springs, and flows through a narrow, very rocky, uninhabited mountain ravine (Figure 1) in eastern Augusta County, Virginia as a tributary of South River of the James River watershed. The stream flows over a rubble, boulder- strewn, and gravel bed of quartzite, apparently dissolving little of the elements conducive to high biological production. It has very soft water and is slightly acid. As shown in Table I, the average methyl orange alkalinity is about 4.69 parts per million, the pH is 6.8, and the free carbon dioxide content is 3.1 parts per million.

According to Mr. R. Lybrook, once chemist for one of the manganese mining companies operating in the valley, the manganese content of St. Mary's River water was relatively high, averaging about 0.316 parts per million. The manganese ore mined in the valley was water deposited and occurred in its purest form as stalactites and stalagmites.

The average width, as reported by McGavock and Davis (1935) on May 17, 1934, was 9 feet upstream from the National Forest boundary to Mine Bank (on map, just above Mine Bank Creek). From this point to its source, the stream averaged 7 feet in width. On that date, the flow was estimated at 7.9 cubic feet per second, with a gradient of 150 feet per mile, in the lower section and 4.3 cubic feet per second and a gradient of 175 feet per mile in the upper section. The survey party making the original survey gave the stream a pool grade of "B" indicating average conditions with many pools of suitable depth and adequate shelter. Suitable depth might be defined as depths of 2 feet or more and adequate shelter may be provided by overhanging banks, by the presence of flat rocks or boulders underneath which trout may hide,

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FIGURE 1. General location of St. Mary's River, George Washington National Forest, Virginia.

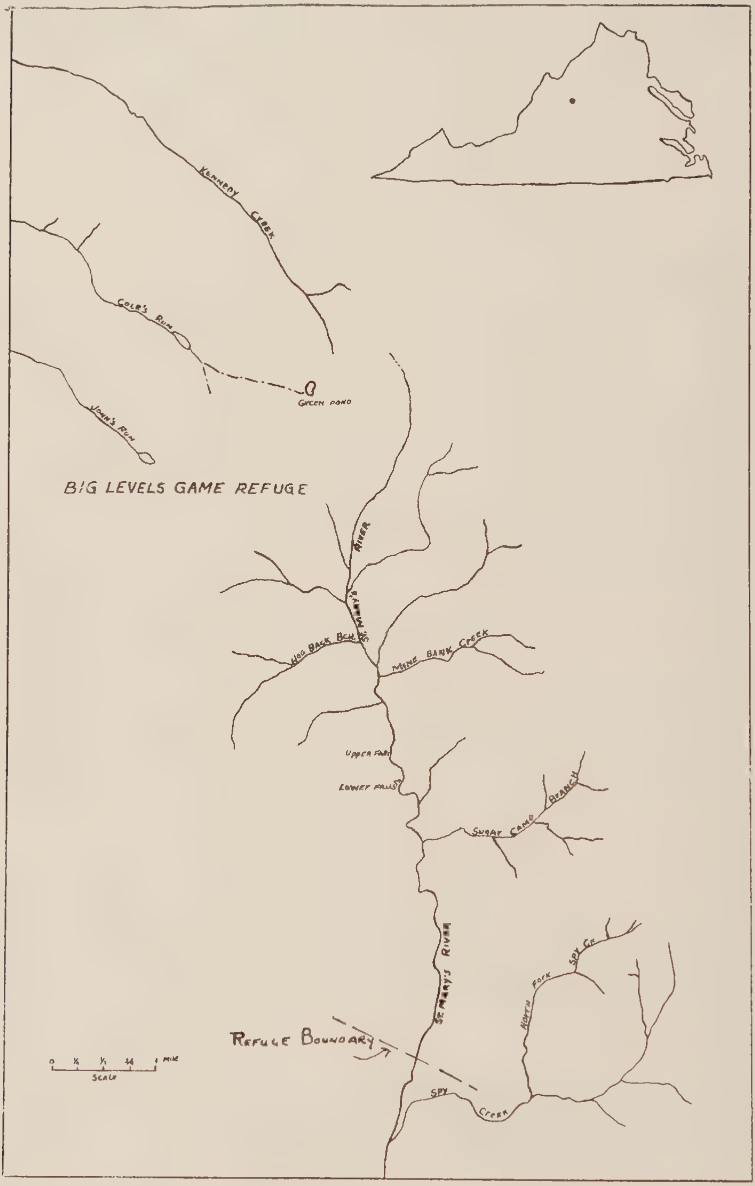

TABLE I.—Chemical Data, St. Mary's River, Virginia.

Date	Water Temperature degrees F.	Hydrogen-ion concentration	Free carbon dioxide p.p.m.	Dissolved oxygen p.p.m.	Methyl orange alkalinity p.p.m
Aug. 29, 1938	63.0	6.9	5.0	8.6	8.75
Sept. 22, 1938	52.5	6.9	3.8	9.4	5.00
Nov. 9, 1938		6.7	2.0	11.1	2.50
Apr. 4, 1939	49.5	6.8	1.5	10.6	2.50
Average	55.0	6.8	3.1	9.9	4.69

or simply by surging water at the head of a pool where depths are usually greatest.

During World War I, a railroad spur was constructed in the St. Mary's Valley to the Red Mountain Mine where manganiferous iron ore was obtained. Mines were also located on Mine Bank Mountain. Residents in the section have stated that during the operation of these mines, the stream was almost continuously roily due to the washing of ore and was unfit for trout. After World War I, the mines and railroad were abandoned; rails were removed and by 1935 the stream was clear and contained a few nice trout. The railroad grade had grown up in briers and brush, and there was no one residing within the game management area. Fly-fishing is difficult due to the canopy of alders which arch over the stream bed and shade it throughout. There are impassable falls at two points about half-way up the stream (see Figure 1). While the stream always has a good flow within the Big Levels Game Management Area, the lower boundary of which is about one mile above the mouth of Spy Creek, the stream bed has been seen entirely dry at the mouth of Spy Creek. On the whole, the stream maintains a better flow than the majority of streams in the George Washington National Forest area, and it has above average natural protection in the form of deep pools and sheltering boulders.

TEMPERATURE CONDITIONS

A continuous record of the temperature of St. Mary's River was obtained with a recording thermometer for the period October 18, 1936, to October 18, 1937, at a point about 0.75 mile below the game management area boundary. Figure 2 depicts temperature conditions in the stream graphically.

A maximum temperature of 68°F., and mean monthly temperatures of 62.75 in June, 63.20 in July, 64.93 in August, and 58.42 in September, were recorded. Daily variations in water temperature, even on the warmest days, were very small due principally to the narrowness of the mountain ravine through which the stream flows and a canopy of alder bushes over the stream. The maximum temperature on the warmest days occurred between 3:00 and 5:00 p.m., while the minimum occurred between 3:00 and 6:00 a.m. There is reason to assume that the effective feeding temperature range for trout lies between 47° and 68°F., which seems probable in the St. Mary's River. If this feeding temperature range is accepted, there were 231 effective feeding days, or parts of days (see Table II) during the period October 18, 1936 to October 18, 1937. The temperature data collected during the early spring of 1937 show only seven days prior to April 15, then the opening day of the trout season, when trout could have fed sufficiently to grow and improve their condition.

The optimum temperature for feeding and growth of brook and rainbow trout is 55-60°F., according to Davis (1929) and Embody (1936). Optimum conditions, therefore, prevail in the St. Mary's River through the greater part of May, June, July, August, and September. According to Embody (1936), brook, brown, and rainbow trout do not cease feeding altogether even at the extreme temperatures of 75 and 77°F., but only a very minor portion of the food offered is consumed and growth is practically nil. It seems doubtful that such extremes of temperature have ever been attained in the St. Mary's River, and

TABLE II.—Number of days in which temperatures of 47° to 65°F. were recorded, St. Mary's River, Virginia.

Month	Year	Number of days
October	1936	14
November	1936	14
December	1936	0
January	1937	8
February	1937	0
March	1937	3
April	1937	21
May	1937	31
June	1937	30
July	1937	31
August	1937	31
September	1937	30
October	1937	18
Total		231

from our own observations it appears that temperature conditions are nearly ideal for growth during at least five months of the year. Needham (1938) notes that brook trout thrive best in streams that show midsummer maximum temperatures around 66°F. Gerrish (1935) observed that the growth rate of trout depends upon the length of the growing season and the inclination to feed within that period. "Water temperature," he states, "is only material in so far as it affects the amount of dissolved oxygen in the water" (*ibid,* p. 14). He believes that trout cannot feed below 40°F., also that even between 40° and 56°F., a too sudden rise of temperature or a sharp fall of atmospheric pressure will put trout off feeding for a while. In the Lambourn, he found trout feeding freely between 40° and 56°F., while from 57° upward the ability to feed decreased rapidly until at 60°F. it ceased. He observed that yearlings were less sensitive to temperature changes than were older fish, and fry were less sensitive than yearlings. In the same paper, he pointed out that trout in such larger rivers as the Kennet fed up to 66°F., and in New Zealand he observed that they fed heavily up to 73°F. and probably higher. In these larger streams he believed that a higher iodine content enabled them to feed at relatively high temperatures.

In connection with the maximum temperatures at which trout feed, it was interesting to note that on July 13, 14, 1937, Dr. James S. Gutsell, Reuben O. Knuth and the writer collected from St. Mary's River 82 brooks and 56 rainbows for growth measurements using artificial flies and spinners. On both of these days, the maximum water temperature was 66°F., while the average daily temperatures were 65.56 and 65.75, respectively. On these days, the trout were obviously feeding vigorously.

The temperature data collected during the early spring of 1937 show there were only seven days prior to April 15 when trout could have fed sufficiently to grow and improve their condition. This information might be offered as an argument against the opening of a trout season, even in this southerly section, much before May 1.

Beginning August 27, 1935, square foot bottom samples, usually 18 to 20, were taken at monthly intervals, except for two or three months in late winter, until August 24, 1937. The samples were collected with a squarefoot bottom sampler using the equipment and technic described by Surber (1936). The results are summarized in Table III. An analysis of the data shows an average wet weight production in grams per square foot of 1.04 grams (dry, 0.22 gram) for the four months during which collections were made in 1935 (August, September, October, and late November). During the nine months, mid-April to mid-December of 1936, the average wet weight of bottom animals was 1.12 grams per square foot (dry 0.28 gram). In 1937, collections were continued from April 1 to August 24. The dry weight of the 1937 bottom samples was not determined, but the wet weight averaged 1.06 grams per square

Figure 2. Temperature data, St. Mary's River, Virginia, showing average daily variations from October 1936 through October, 1937.

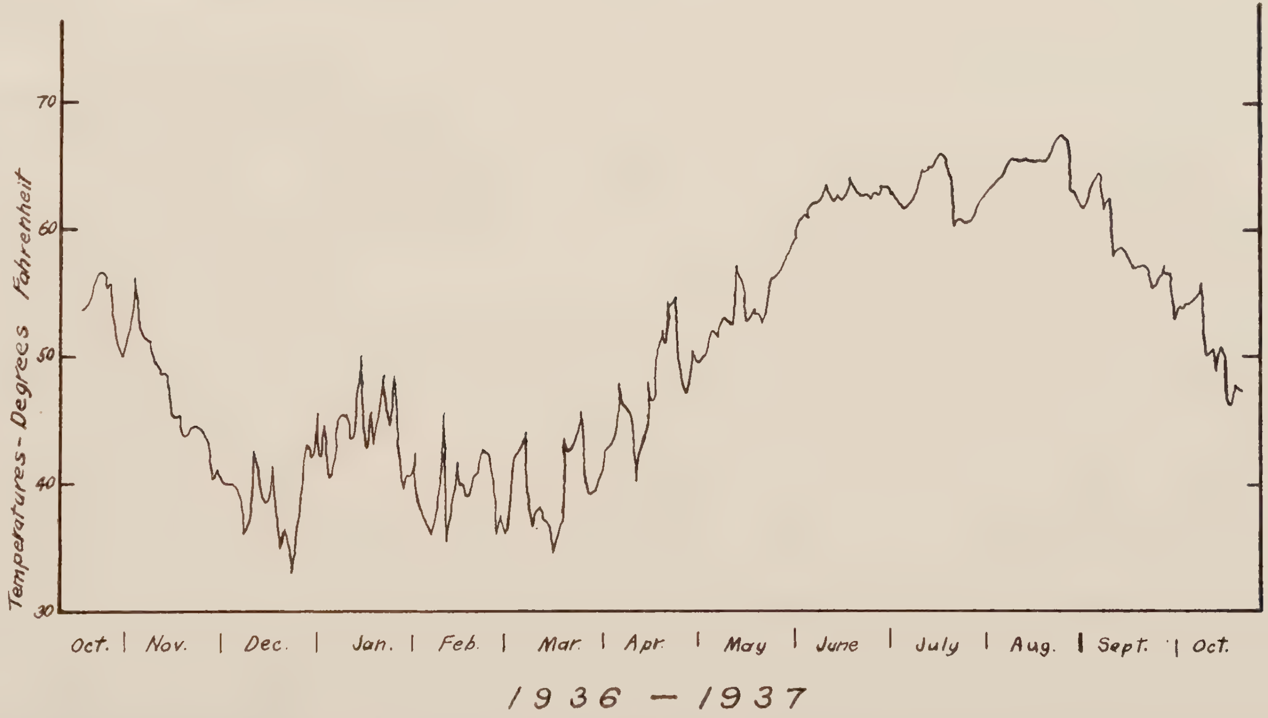

TABLE III.—Bottom fauna of the St. Mary's River (riffles only). Average number of organisms per square foot.

	Aug. 27, 1935	Sept. 26, 1935	Oct. 28, 1935	Nov. 26, 1935	Jan. 7, 1936	April 13, 1936	May 15. 1936	June 17, 1936	July 14, 1936	Aug. 14, 1936	Sept. 16, 1936	Oct. 16. 1936	Nov. 17, 1936	Dec. 17, 1936	April 1, 1937	May 8, 1937	June 3, 1937	July 13, 1937	Aug. 24, 193
Number of samples	20	20	20	13	18	16	15	20	18	20	19	19	19	16	18	19	20	20	20
Total number of animals	2.044	2,212	2.224	1.310	1,545	1,049	481	1 120	924	1 351	2.470	1.986	1,810	886	1,440	763	680	2,362	2,887
Average number per sample	102.20	110.70	110 20	100.80	86.00	66.00	32.10	56.00	51.33	67.55	130.00	104.50	95.30	55.40	80 00	44.88	34.00	118.10	144.35
Average wet weight per sample	1.00	1.15	1.14	0.86	0.82	1 08	0.42	1.65	1.18	1.96	1 28	1.26	0 65	1 05	1.06	0.68	0.58	1.42	1.58
Average dry weight per sample	0.21	0.25	0.24	0.17	0.16	0.23	0.10	0.41	0.42	0.48	3.20	0.30	0.15	0.23	-	-	-	-	-
Oligochaeta (tube worms)	0.80	2.15	1.85	1.69	0.67	0.27	0.30	0.50	0.50	0.05	0.16	0.75	0.11	0.33	1.10	0.30	0.10	0.65	0.95
Crustacea (crayfish):																			
Cambarus	1.05	-	0.03	0.23	0.17	0.31	0.53	0.70	0.56	1.20	0.52	0.37	0.16	0.19	0.17	0.20	0.45	0.55	0.55
Trichoptera (caddis fly larvae)																			
Cheumatopsyche & Hydropsyche	42.60	50.00	38.10	29.31	18 28	13.94	8.13	6.85	26.17	29.00	50 05	28.11	17.79	9 25	8.50	2.70	2.45	2.34	30.65
Dolophilodes	1.05	6.40	14.70	1.23	0.33	0.94	0.47	5.60	2.50	1.30	4.00	1.99	4.26	1.06	0.50	0.20	0.70	6 90	5.70
Rhyacophila fuscula	0.05	0.35	0.90	0.15	0.59	0.31	-	0.85	0.44	0 35	-	0 11	0 95	0 13	0.40	0.16	0.45	0.05	-
Rhyacophila torva	0.20	0.40	1.75	1.23	0.44	1.19	0.27	0.40	0.39	0.20	0.47	1.95	0 89	0 75	0.75	0.40	0.20	0.40	0.05
Brachycentrus	-	-	1.45	2.31	1.61	-	0.07	0.05	-	-	-	0.11	1.21	1.75	0.60	0.20	0.20	-	0.35
Miscellaneous	5.75	1.60	0.15	0.53	1.69	0.31	0.82	1.85	1.66	2.90	1.00	0.32	0.32	0.50	0.80	0.70	0.30	1.40	2.60
Plecoptera (stonefly nymphs)																			
Leuctra, Alloperla, etc.	12.80	2.10	1.50	2.23	1.78	2.25	1.13	1.45	1.33	1.20	2.53	14.28	8.58	5.94	3.90	3.90	1.15	21.40	14.35
Peltoperla	0.90	5.30	1.80	3.15	1.06	2.56	0.53	0.70	-	0.10	5 26	2.58	0.84	0.38	0.80	0 36	0.10	7.85	4.60
Perla and Acroneuria	1.95	3 80	2 35	3.69	2.39	2.69	0.53	2.15	2.33	2.75	4.05	4.73	3 37	1 25	3.20	1.60	1.60	4.35	6 95
Pteronarcys	0.10	0.30	0.20	-	0.06	-	-	0.45	0.17	0.60	0.42	0.16	0.16	0.31	0.10	-	0.15	0.20	0.15
Nemoura	-	-	-	-	-	2.31	0.20	0.55	-	-	-	-	0 05	-	0.20	0.26	0.05	-	-
Miscellaneous	0.05	0.10	2.75	2.20	3.17	0.19	0.33	0.10	-	0.25	-	5.53	0.63	3.31	0.10	0.31	-	0.80	-
Odonata (dragonfly nymphs)																			
Aeschna	-	-	-	-	-	0.06	0.07	-	0.44	0.60	0.21	0 11	-	0.13	-	0.05	-	0.15	-
Lanthus	0.05	-	-	-	-	-	-	0.05	0.11	0.10	0.05	0.05	-	-	-	-	-	-	-
Miscellaneous	0.30	0.20	0.35	0.08	-	0.06	0.07	0.05	-	-	-	-	0.05	0.13	-	0.05	-	0.05	0.20
Ephemerida (mayfly nymphs)																			
Stenonema	11.65	16.75	13 30	20 92	10 41	4.75	3 53	2 85	2.17	6.05	33 68	20 53	12 91	10.44	8 20	3.40	1 50	3 30	11.75
Baetis and Pseudocloeon	6.55	8.60	1.00	0.31	1.50	0.75	1.47	3.00	3.00	2.65	5.26	1.79	0.58	-	2.10	1.40	2.85	17.30	8.25
Paraleptophlebia	0.55	0.50	17.20	7 62	9.17	1 31	2 00	1.95	0.78	0.35	3.15	17.84	19.47	9 50	6.70	4.80	5.15	4 65	4.55
Iron	2.85	2.35	3.30	10.08	20.28	15.69	2.87	7.50	1.39	5.20	2.37	0.58	10.89	2.06	17.40	5.70	3.10	3.00	0.85
Ephemerella	0.65	0.55	3.20	5.92	4.78	10.00	2.87	6.95	0.50	2.05	0.52	0.05	3.32	1.81	6.30	2.80	1.60	1.60	1.60
Isonychia	1.40	-	1.05	0.08	-	-	0.20	0.10	-	0 25	0.47	0.16	0.21	0.13	0.10	-	-	-	0.45
Miscellaneous	-	2.35	0.30	-	-	-	1.53	-	-	0.10	-	-	-	-	1.10	-	0.20	0.05	0.05
Neuroptera (fish-flies)																			
Nigronia	1.15	0.20	0.30	0.31	1.67	0.25	0.13	0.53	0.17	1.10	1.11	0.68	0.42	1.53	0.10	0.60	0.60	1.90	2.75
Miscellaneous	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.13	-	-	-	-	-
Coleoptera (beetles)																			
Parnid adults	0.80	0.15	0.05	-	0.06	-	-	0.10	0.06	-	0.84	0.11	0.05	-	0.05	-	-	0.20	0.45
Parnid larvae	0.40	0.15	0.55	0.23	-	0.13	-	0 05	-	0.10	0.11	0.42	0.21	-	0.30	-	0.15	0.20	0.10
Psephenus	0.30	0.05	-	-	-	-	0.13	0.05	-	-	0.05	0.16	-	-	-	0.10	0.10	0.05	0.05
Miscellaneous	0.05	-	0.05	0.08	0.11	-	-	-	-	-	-	-	-	-	-	0.05	-	0.05	-
Diptera (fly larvae)																			
Atherix	1.30	0.75	0.45	0.23	1.22	0.25	0.13	0.50	0.94	7.30	10.74	3.26	4.47	2.31	1.10	0.70	1.25	1.20	3.30
Chironomidae	5.55	5.80	1.50	5.23	3.06	0.69	3.27	5.75	3 28	0 50	0.89	0.68	0.52	0.75	2.80	4.80	3 30	12.00	40.25
Eriocera	0.80	0.65	0.90	0.31	0.56	0.63	0.40	0.50	0.22	0.65	0.95	1.52	1.52	0.38	1.10	0.60	0.70	1.10	0.90
Simulium	0.15	0.45	0.25	-	0.17	2.94	0.13	1.45	1.89	0.01	0.52	0.05	0.26	0.31	10.40	-	1.05	2.50	0.35
Antocha	0.80	0.50	0.65	0.15	-	0.19	-	0.25	0.06	0.10	0.05	0.68	0.63	0.06	0.90	0.50	0.15	0.20	0.20
Miscellaneous	0.05	-	0.20	0.15	0.06	0.13	-	0.35	0.17	0.15	-	-	0.11	0.06	0.40	0.16	0.15	0.05	0.40
Vertebrates:																			
Salamanders	0.45	0.20	0.20	0.54	0.39	0.25	0.20	0.20	0.06	0.20	0.05	0.37	0.37	0.38	-	0.10	0.10	0.10	0.20
Miscellaneous organisms:	0.10	0.25	-	-	-	0.13	-	0.05	0.06	0.20	0.11	0.16	-	0.06	-	0.20	0.10	0.20	0.80

foot. Again in 1938, a series of 10 samples per month was collected from March 23 to November 9. These samples averaged 1.37 grams per square foot. This average was slightly above that of the three previous years when larger numbers of samples were collected, but it serves to give additional evidence that the riffle areas average slightly more than 1.00 gram, wet weight, of potential food organisms per square foot per year.

This quantity of potential fish food organisms is believed to be about average for good mountain streams in this area.

The bottom fauna of Kennedy Creek, a smaller stream nearby in the Big Levels Refuge, and Spy Creek, a tributary of St. Mary's River, were studied during the same period in 1935, 1936, and 1937. Kennedy Creek had an average wet weight of 1.75 grams during this period while Spy Creek, also a small stream, averaged 1.80 grams per square foot during 1935-1926 as compared to the average of 1.07 grams per square foot in the St. Mary's River during the same period.

The data in Table II indicate that bottom animals are least abundant during late spring and early summer at the time when insect emergence is at its height. Bottom animals are most abundant during August, September, and October. Thus, plantings of fingerling trout, if made during the latter three months, are likely to find stream conditions at their best with respect to bottom foods.

Severe floods often occur during the spring period as they did on March 13, 1926 and again on April 26, 1937, when record or near record floods occurred. Their effect on abundance of stream animals is highly destructive, but considerable recovery usually is noted within one to three months' time.

Caddis larvae belonging to the Hydropsychidae, *Cheumatopsyche* and *Hydropsyche,* with brown or bright green bodies, were always present in considerable numbers in all bottom samples. The small caddis larvae of *Dolophilodes distinctus* Walker, with white bodies and bright yellow heads, were usually present. The larger *Rhyacophila fuscula* Walker, and *Rhyacophila torva* Hagen were quite common but did not occur in all samples. In sampling St. Mary's River during a DDT project during 1947, Hoffmann and Merkel (1948) found the genus *Cheumatopsyche* to predominate over *Hydropsyche* in their samples. They list *Hydropsyche* (near *slossonae* Banks) and the small pink-bodied Psychomyiidae.

The small turtle-shell-like cases of coarse sand grains containing the larvae of the caddis fly *Goera calcarata* Banks often occur over the rocks and boulders in abundance as does *Brachycentrus* and other caddis larvae. These are not readily removed from stones and are undoubtedly more abundant than the samples indicate.

The mayflies play an important part in the ecology of all of these mountain streams. The forms with much flattened heads and bodies, often large in size, move swiftly as one lifts stones from the water. The reddish-legged nymphs of *Stenonema fuscum* Clemens are abundant and *Stenonema varium* Traver, and *Stenonema pulchellum* Walsh are common. *Stenonema heterotarsale* McDunnough occurs in small and unimportant numbers. The mayfly nymphs of *Paraleptophlebia guttata* McDunnough and *Paraleptophlebia mollis* Eaton are nearly always present in bottom samples from St. Mary's River, regardless of stream velocities.

Among the common species of mayflies in the stream are *Ephemerella subvaria* McDunnough and the swift-moving *Isonychia sadleri* Traver. Species of *Baetis* and *Pseudocloeon* also have been recorded. Hoffman and Merkel (1948) recorded *Baetis cingulatus* McDunnough and *Pseudocloeon carolina* Banks in relatively small numbers.

A few stonefly nymphs are always present in St. Mary's River samples. Among the most conspicuous, largest and most active of these are the carnivorous *Acroneuria abnormis* Newman and *Acroneuria lycorias* Newman. The large *Pteronarcys proteus* nymphs are found in riffle samples containing decaying leaves. These samples also contain many of the small reddish brown roach-like stonefly nymphs of *Peltoperla arcuata* Needham which feed on plant debris. Among the smaller, swift running, not so numerous but conspicuous stonefly nymphs are the brilliant *Neophasganophora capitata* Pictet and *Isoperla bilineata* Say. Of lesser importance among the larger nymphs are such species as *Acroneuria depressa* Needham and Claasen and *Perla hastata* Banks. The stonefly nymphs of *Isoperla similis* Hagen are relatively uncommon.

Small stonefly nymphs of *Leuctra, Alloperla, Capnia,* etc., were common in the bottom samples, but rearing will probably be required before they can be identified to species.

The larvae of the fish-fly *Nigronia serricornis* Say, although unimportant numerically when compared with the abundance of the organisms listed above, are found in the majority of samples, and their relatively large bulk makes them one of the most important animals. The crayfish *Cambarus b. bartoni* (Fabricius) are less numerous than *Nigronia* but are still larger in size and are very important trout food organisms.

In 1938, surface current velocities were determined at the various points where bottom samples were ordinarily taken to determine, if possible, the effect which various current velocities had on the abundance and distribution of the bottom organisms. In making these surface current velocity measurements, a round cork of the type generally used by bass fishermen in this region was timed by a stop watch as it passed over a known distance. A variable distance was employed through which to float the cork, since it was impossible to use a standard distance,

TABLE V.—Abundance of several genera of aquatic organisms at different velocities, St. Mary's River, Virginia, 1938.

				Mayfly nymphs				
Number of samples	Velocity Feet per second	Crayfish Cambarus	Fish-fly larvae Nigronia	Iron	Baetis	Ephemerella	Paraleptophlebia	Stenonema
2	0.50-0.99							
Total number		2	0	1	7	2	18	11
Average number per sample		1	0	0.50	0.35	1.00	9.00	5.50
Frequency		1	0	1	1	1	2	2
Percent		50.00	0	100.00	50.00	50.00	100.00	100.00
14	1.00-1.49							
Total number		9	37	10	97	18	305	157
Average number per sample		0.64	2.64	0.71	6.93	1.29	21.79	11.21
Frequency		6	12	3	11	7	14	13
Percent		42.86	85.72	21.43	78.57	50.00	100.00	86.67
19	1.50-1.99							
Total number		7	20	22	82	62	334	193
Average number per sample		0.37	1.05	1.16	4.32	3.26	17.58	10.16
Frequency		4	10	8	12	12	19	18
Percent		21.05	52.63	42.11	63.16	63.16	100.00	94.74
14	2.00-2.49							
Total number		6	32	39	108	69	326	90
Average number per sample		0.43	2.29	2.79	7.71	4.93	46.57	6.43
Frequency		6	12	6	13	10	14	14
Percent		42.86	85.72	42.86	21.43	71.43	100.00	100.00
7	2.50-2.99							
Total number		2	18	8	30	9	93	14
Average number per sample		0.29	2.57	1.14	4.29	1.29	13.29	2.00
Frequency		1	6	3	6	4	7	4
Percent		14.29	85.71	42.86	85.71	57.14	100.00	57.14
4	3.00-3.49							
Total number		1	4	30	33	7	96	47
Average number per sample		0.25	1.00	7.50	8.25	1.75	24.00	11.75
Frequency		1	1	4	2	3	4	4
Percent		25.00	25.00	100.00	50.00	75.00	100.00	100.00

TABLE V. (continued)

	Stonefly nymphs			Caddis fly larvae			Fly larvae		
Number of samples	Perla and Acroneuria	Leuctra	Alloperla	Cheumatopsyche and Hydropsyche	Rhyacophila	Dolophilodes	Hexatoma	Atherix	Antocha
2									
Total number	2	8	49	27	0	7	4	2	2
Average number per sample	1.00	4.00	24.50	13.50	0	3.50	2.00	1.00	1.00
Frequency	1	1	2	2	0	2	2	1	1
Percent	50.00	50.00	100.00	100.00	0	100.00	100.00	50.00	50.00
14									
Total number	34	55	147	843	5	24	13	10	24
Average number per sample	2.43	3.93	10.50	60.21	0.36	1.71	0.93	.71	1.71
Frequency	7	11	10	12	3	10	6	5	10
Percent	50.00	78.57	71.43	85.72	21.43	71.43	42.86	35.71	71.43
19									
Total number	39	20	126	754	8	64	39	13	60
Average number per sample	2.05	1.05	6.63	39.68	0.42	3.37	2.05	0.68	3.16
Frequency	15	8	16	19	6	14	11	9	14
Percent	78.95	42.11	84.21	100.00	31.58	73.69	57.89	47.37	73.69
14									
Total number	74	52	131	756	6	60	24	26	55
Average number per sample	5.29	3.71	9.36	54.00	0.43	4.23	1.71	1.86	3.93
Frequency	12	11	10	13	3	12	10	7	10
Percent	85.72	78.57	71.43	86.67	21.43	85.72	71.43	50.00	71.43
7									
Total number	14	45	27	339	0	76	10	7	23
Average number per sample	2.00	6.43	3.86	48.43	0	10.86	1.43	1.00	3.29
Frequency	4	4	5	7	0	6	5	4	5
Percent	57.14	57.14	71.43	100.00	0	85.71	71.43	57.14	71.43
4									
Total number	38	36	33	791	2	131	9	4	11
Average number per sample	9.50	9.00	8.25	197.75	0.50	32.75	2.25	1.00	2.75
Frequency	4	4	3	4	2	4	4	4	3
Percent	100.00	100.00	75.00	100.00	50.00	100.00	100.00	100.00	75.00

particularly in fast water.

Table IV shows the results of these surface velocity determinations for 57 samples which are compiled with respect to average wet weights of bottom animals for each of the six surface velocity groups.

In the tabulations showing abundance of various genera at different velocities. Chironomidae larvae were omitted, although they were very likely present upon the stones in each sample. The mode of existence of the tendipedid species, usually in silk tubes on the surfaces of stones, makes accurate determinations of their abundance impossible because they dwell in the crevices and depressions from which they are not easily dislodged. They are, none the less, among the most important bottom fauna of the stream and very likely are important food organisms for small fish. Their wet weight per square foot in riffle samples is usually insconsequential.

TABLE IV.—Frequencies of occurrence of certain surface velocities and average number and wet weight of bottom animals in 60 bottom samples collected during 1938, St. Mary's River, Virginia.

Velocity in feet per second	Number of bottom samples	Average number of bottom animals per square foot	Average wet weight grams per square foot
0.50 - 0.99	2	99.00	3.33
1.00 - 1.49	14	147.86	1.31
1.50 - 1.99	19	115.47	1.01
2.00 - 2.49	14	152.21	1.23
2.50 - 2.99	7	124.71	1.55
3.00 - 3.49	4	339.25	3.16

These data indicate that most of the samples were collected at surface velocities of 1.00-2.5 feet per second and that the largest number of samples was taken at 1.5 - 1.99 feet per second. The collections were not sufficient to indicate definitely the effects of different velocities on the abundance of bottom animals at the various velocities. In the 0.50 - 0.99 group, only two samples were obtained. One of these contained a large crayfish which brought the average wet weight much above the average wet weight of succeeding groups which had larger numbers of samples. Between velocities of 1.00 - 2.50 feet per second, the average weight and abundance of bottom organisms remain about the same. In the four samples with velocities of 3.00 - 3.49 feet per second, both the numbers and weight of organisms increase decidedly. In these samples, the net spinning caddis larvae of the family Hydropsychidae alone, averaged 198 per square foot.

Table V lists the principal genera of bottom animals in St. Mary's River for different surface velocities of the stream. These data show, for 1938, that besides Hydropsychidae, the mayfly nymphs of *Paraleptophlebia* were present in every sample regardless of velocity, but as might be expected, they were most abundant at velocities of 2.00 - 2.49 feet per second. It is almost impossible, however, to determine accurately velocities in the actual habitats of the animals among the stones.

The bottom fauna data for St. Mary's River presented in this report were loaned for a student problem to Mr. S. Lee Crump, Laboratory of Limnology and Fisheries of Cornell University, Ithaca, New York, to determine statistically whether the weight of organisms could be estimated from the number of organisms in the sample; whether wet weight, determined after draining the organisms for one minute on blotting paper was a more efficient means of expressing weight of organisms than dry weight determined by drying the organisms, until thoroughly dry in an oven at 60° C., and whether an analysis of variance would show that the differences between the amounts of bottom animals in different months were real differences.

He found (1) that weight of organisms could not be estimated from the number of organisms, probably because certain large forms caused a higher weight disproportionate to the number of organisms; (2) that wet weight and dry weight are about equally efficient from the standpoint of variability; (3) that it would be possible to estimate one weight measurement from the other, if the proper factor was calculated; (4) that there were significant differences between the amounts of bottom animals in different months.

NOTES ON THE FOOD OF TROUT IN ST. MARY'S RIVER

Stomachs of 37 brook trout and 14 rainbow trout were taken from anglers' catches in St. Mary's River during the open season, May 15 to June 15, 1936, for examination. Of particular interest were (1) the numerical predominance of terrestrial over aquatic food animals, (2) the evident importance of crayfish (even of good-size) as food for small trout, (3) the presence of considerable quantities of filamentous algae in five of fourteen rainbow trout although algae were absent from all the brook trout, (4) the greater preference of the rainbow trout, as compared with the brook, for aquatic forms and (5) the presence of nematode parasites in nearly all of the stomachs. The latter may have originally been in the bodies of terrestrial insects consumed by the fish.

Of the 37 brook trout stomachs, approximately 46 per cent contained crayfish, 41 per cent contained caddis flies (all stages), 38 per cent contained stoneflies (all stages), 22 per cent contained mayflies (all stages) and 11 per cent contained fish. Not more than 8 per cent (3) contained recognizable remains of other types of aquatic food animals not listed above. Among terrestrial animals, beetles were found in 86.5 per cent, flies in 65 per cent, ants, bees, etc., in 65 per cent, spiders in 27 per cent, grasshoppers and crickets in 11 per cent and moths or butterflies in 11 per cent. Nematode parasites were found in 97.3 per cent of the brook trout with an average of 21.3 per fish.

Of the 14 stomachs of rainbow trout, 79 per cent contained stoneflies, 57 per cent contained caddis flies, 50 per cent contained aquatic flies, midges, etc. (all stages), 36 per cent contained fish and 36 per cent contained algae. Terrestrial beetles were found in 86 per cent, terrestrial flies in 43 per cent and ants, bees, etc. in 29 per cent. Nematodes were found in only 92.9 per cent but were relatively more numerous (37.5 per fish) than in brook trout.

Metzelaar (1929), following a study of the food of 47 rainbow trout in Michigan, observed that the outstanding feature of the rainbow diet was the 15 per cent vegetation, formed largely by filamentous green algae. Surber (1936) found algae in 28 out of 131 (21.3 per cent) rainbow trout stomachs collected in 1934 from fish in Big Spring Creek. Leesburg, Virginia.

Terrestrial flies constituted 62 per cent of the number of animals found in the stomachs of brook trout (18 per fish); terrestrial beetles 16.4 per cent (4.8 per fish); ants, bees, etc., 10.7 per cent (3.1 per fish); and spiders 1.1 per cent (0.3 per fish). Among aquatic animals, caddis flies were most numerous, 3.7 per cent; stoneflies next, 2.2 per cent; and crayfish a close third, 2.0 per cent.

The food of the rainbow trout examined was more largely aquatic. Terrestrial flies constituted 45.4 per cent; terrestrial beetles, 16.9 per cent; ants, bees, etc., 3.4 per cent; aquatic flies, midges, etc., 8.2 per cent, and crayfish 2.4 per cent.

It is well that terrestrial insects make such a large contribution to the food of trout at a time when emergence of insects and freshets, or floods, reduce the supply of truly aquatic organisms.

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SUMMARY AND CONCLUSIONS

1. A study of physical conditions shows that St. Mary's River within the Big Levels Game Management Area and for a distance of at least 1 mile below the area boundary is suitable for brook trout. The maximum temperature during a year of continuous observation was 68°F. Shelter and pool conditions are probably better than average for most streams of the George Washington National Forest.
2. Chemical analysis revealed that the St. Mary's River water is very soft and averaged only 4.69 parts per million of methyl orange alkalinity in terms of calcium carbonate. It is an acid stream having an average pH of 6.8.
3. A study of temperature conditions showed that there were 231 days in a year during which temperatures ranged between 47°F. and 68°F. when trout grow and feed well. These temperature data also demonstrated that trout have little opportunity in which to grow in the spring prior to usual opening of the Virginia trout season about April 20.
4. Bottom organisms in riffle samples averaged 1.07 grams wet weight (0.25 gram dry) per square foot during the period August, 1935 to August, 1937. This amount of bottom fauna production probably represents average richness. Two of the smaller trout streams in the Big Levels Game Management Area—Kennedy Creek and Spy Creek—were also investigated at the same time. These averaged slightly higher: 1.75 and 1.80 grams wet weight per square foot, respectively. Much the same organisms occurred in the three streams. The data indicate that late spring and early summer are periods when bottom organisms are least abundant. Trout planted in the fall or early spring would find bottom foods most abundant. The severe floods of March, 1936 and April, 1937 apparently did not do protracted damage to the bottom fauna, although stream organisms averaged fewer in number during the period immediately following each flood.
5. The food found in the stomachs of 37 brook trout and 14 rainbow trout taken from anglers' catches during the period May 15 to June 15, 1936, was examined microscopically. These examinations showed (a) a numerical predominance of terrestrial over aquatic food animals, (b) that crayfish are apparently important food organisms,

(c) that rainbow trout eat quantities of filamentous algae, which brook trout do not eat, (d) that rainbow trout seem to have a greater preference for aquatic forms of food than brooks, and (e) that nematode parasites were abundant in all trout stomachs in the collection.

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RECORD OF THE LARVAL TREMATODE *HIMASTHLA QUISSETENSIS* (MILLER AND NORTHUP, 1926) STUNKARD, 1934 IN THE CLAM, *MYA ARENARIA*

Stunkard (1938; Biol. Bull. 75: 145–164) experimentally determined the life cycle of *Cercaria quissetensis* (Miller and Northup, 1926) and referred it to the echinostome genus *Himasthla*. He reported encystment in the mantle, gills, and foot of six species of bivalve mollusks experimentally infected. Gulls of the genus *Larus* were reported as final hosts.

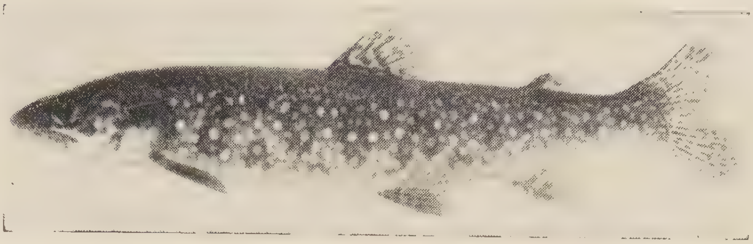
The natural occurrence and frequency of the metacercariae in a bivalve intermediate host have not been reported. Observations made during the summer and fall of 1950 in Essex County, Massachusetts indicate that the soft clam, *Mya arenaria,* is an important vector in the transmission of this parasite. Cercarial producing specimens of the mud snail, *Nassa obsoleta,* were readily collected and experimental infections of *Mya* were accomplished for comparative identification. Samples of *Mya* from Merrimack Bay, Plum Island Sound, and Annisquam River show a high incidence of infection ranging from 43 to 100 per cent. Among these samples, the degree of infection ranges from 1 to 99 larvae per clam with larger clams showing a higher degree and frequency of infection; frequency exceeds fifty per cent when mean size of sample exceeds 50 mm. In natural infections, the predominant foci are the palps and gills; few metacercariae were observed in other tissues.

Evidence of widespread range and frequency of these larvae in *Mya* was found in a sample lot of fifty specimens from the region of St. Andrews, N.B., Canada. Of these, forty-five, or ninety per cent, were infected with the larval parasite.

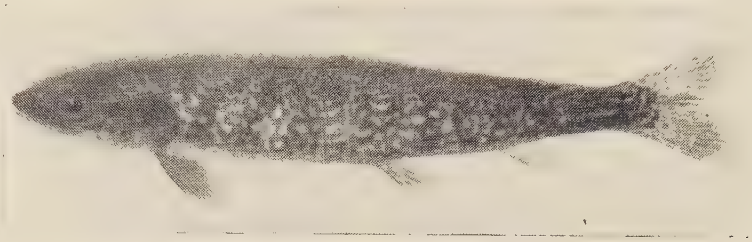
These observations and a consideration of the coincident habitat suggest that *Mya arenaria* is an important vector of *H. quissetensis* throughout its mutual range with *Nassa obsoleta.*—JOSEPH R. UZMANN, *U. S. Fish and Wildlife Service, Newburyport, Massachusetts.*

Progress Report on the Study of Great Lakes Trout

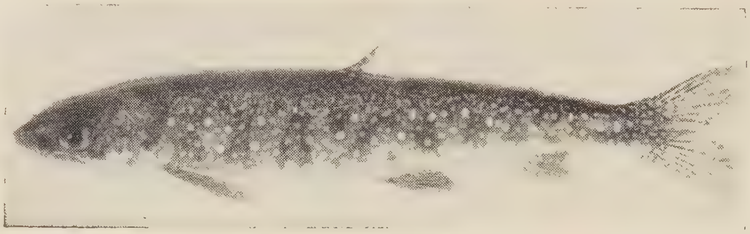
By Dr. John Van Oosten
Chairman, Great Lakes Lake Trout Committee



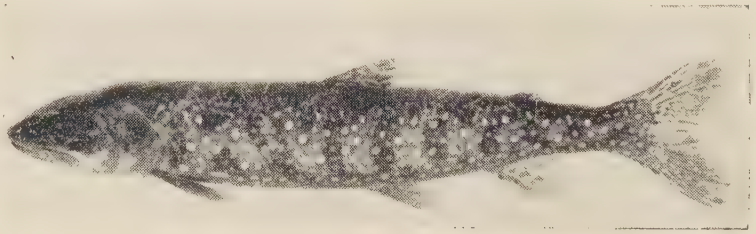
An Unmarked Two-Year-Old Lake Trout



Lake Trout Showing No Regeneration of the Back and Fatty Fins



Trout Showing Partial Regeneration Back and Fatty Fins



Trout with Almost Complete Regeneration of Back and Fatty Fins

To what extent have the hatcheries contributed to the populations of lake trout in the Great Lakes? Hundreds of millions of fry and fingerlings have been planted in these lakes and thousands of dollars have been expended. Yet no one actually knows how many of these fish have ever entered the commercial catch or the sportsmen's creel. Attempts to demonstrate beneficial results from the planting of whitefish and yellow pikeperch fry have failed repeatedly.

In order to obtain some definite information on this exceedingly controversial question of trout management and on related problems, the Wisconsin Conservation Commission called a conference of representatives from all states fronting Lakes Michigan and Superior and from the U. S. Fish and Wildlife Service. At that meeting, which was held on December 8, 1943, at Madison, Wisconsin, it was decided to initiate a project of cooperative research on Lake Michigan, and a Lake Trout Committee (*) was established to draw up a program and work out the mechanical details of joint action.

The first formal meeting of the committee was held at Chicago, Illinois, on April 25, 1944. A series of 23 questions was submitted for discussion. Out of this conference and subsequent meetings and discussions came the following program of action:

1. Continue to plant in Lake Michigan as many lake trout fry and fingerlings as possible in 1944, 1945, and 1946, but fin-clip at least 10 per cent of the fingerlings in each of these years.

2. Permit no planting of lake trout in Lake Michigan in 1947, 1948, and 1949.

3. Plant any lake trout fry or fingerlings produced from Lake Michigan in 1947-49 in Lake Huron or inland waters, and fin-clip at least 10 per cent of the fingerlings deposited in Lake Huron.

4. Fin-clip under the joint jurisdiction of Michigan and Wisconsin officials fingerlings reared at the U. S. Fish and Wildlife Service's hatchery at Charlevoix, Michigan.

5. Release the marked fingerlings in the vicinity of the Fox Islands and on the Big Reef, 9 miles northwest of Charlevoix in northeastern Lake Michigan (1944-46), and off Alpena (Scarecrow Island), Michigan, in Lake Huron (1947-48). (No lake trout were reared at Charlevoix in 1949.)

6. Pay a reward of $2.00 for the delivery of any Lake Michigan and Lake Huron baby lake trout with missing or deformed fins or for deformed fins from trout of legal size, with accompanying information on date and place of capture and other requested data (gear, depth of water, length, weight, sex, scales).

7. Retain samples of the fin-clipped trout as well as of non-clipped controls in hatchery ponds to determine (a) the effect of marking on survival, (b) the extent of fin regeneration, (c) any differential rate of growth, and (d) any differential mortality in the presence of or exposure to fish predators—all of these experiments to be conducted by Michigan at Marquette.

8. Collect biological data (length, weight, sex, maturity) and scales from commercially caught lake trout; determine the frequency of occurrence of deformed or missing fins among non-hatchery (wild) lake trout; and as opportunity permits tag young and adult lake trout—all of this field work to be done on Lakes Michigan and Superior by the cooperating agencies equipped for it.

9. Determine the per cent of hatchery and non-hatchery (wild) lake trout of commercial lifts of gillnets and other gear at different localities on Lakes Michigan and Huron, and check the thoroughness and accuracy of reporting by fishermen.

10. Adopt a uniform method of collecting statistics of the commercial

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* *Since September 10, 1946, the Province of Ontario has also been represented on the committee.*

catch to make possible, among other things, a study of the correlation between hatchery plantings and subsequent yields of lake trout.

11. Adjust where necessary the closed season for lake trout on Lake Michigan to cover adequately its spawning period, and strictly enforce this season.

12. Determine, when feasible, by taxonomic and other studies the distinguishing characteristics of any races of lake trout that may be present in the Great Lakes.

13. Distribute posters and otherwise publicize the fin-clipping experiment and reward.

Although the heart of the program (fin-clipping) was set up as a 6-year project (1944-49) it is evident that the investigation must continue over a much longer period of time before final conclusions on all objectives can be reached. Nevertheless, progress of various phases of the work was reviewed at various times not only by committee members but also by individual investigators (Gerald P. Cooper, K. G. Fukano, and David S. Shetter of Michigan; Elmer F. Herman and Matt Patterson of Wisconsin; Frank W. Jobes, U. S. Fish and Wildlife Service; G. C. Armstrong, Ontario). At no time, however, have these various reports been integrated into one report for convenient reference. Now—at the end of the 6-year period—seems to be an appropriate time to do so. I am greatly indebted to both the committee members and the several investigators for the use of their reports.

The various reviews indicate that on the whole good progress has been made. All or part of every objective listed above has been carried out except items in 10, 11, and 12. All of the experiments listed in 7 above have been concluded. In the following, tentative conclusions or final results on the main points of interest have been briefly summarized or compiled in condensed form.

Lake Michigan

1. In 1944-46 some 3,277,402 lake trout fingerlings from the Charlevoix hatchery were planted in September in the vicinity of the Fox Islands and east thereof. Of this total 411,394 (12.6 per cent) were fin-clipped as follows:

Year	Fin Removed	Number Clipped	Per Cent of Total Planted	Average Length (Inches)
1944	back (dorsal) and fatty (adipose)	100,280	9.2	2.9
1945	right front (pectoral)	159,712	12.3	3.2
1946	left front	151,402	17.1	3.2

2. Recoveries up to January 1, 1950, of lake trout presumably fin-clipped and their average lengths are shown in Table I. There were recovered 35 specimens tentatively recognized as hatchery fish marked in 1944, 902 clipped in 1945, and 70 in 1946. (An additional 24 trout with the 1946 mark and 33 with the 1945 mark were taken in January - February, 1950. None has been reported for March). Some 205 trout were classified as doubtful, that is, there was good evidence (fish too large, wrong fins missing, fin slightly abnormal, place of recovery too far from area of release, etc.) that these fish were not hatchery specimens. Of the grand total recorded in Table I (1,212) 1,007 (83.0 per cent) individuals were considered hatchery fish of which 902 (89.6 per cent) belonged to the 1945 year class and 27 (2.7 per cent) were of legal size. The recoveries represent a 0.24 per cent actual return from the 411,394 fin-clipped fish (1 out of every 409) or an estimated 7,866 fish from the 3,277,402 planted in 1944-46. No data are available on the actual numbers of normal-finned baby trout that were taken in or near the areas of release or recoveries.

3. The baby trout taken in the State of Michigan in 1947 and recorded as hatchery fish were, with possibly three exceptions, recovered in the general area of release, the enclosure roughly bounded by lines drawn from Charlevoix to South Fox Island to Gull Island to Squaw Island to Waugoshance Point. The three specimens (which may not have been hatchery fish) captured outside this area were taken off Pierport, between South and North Manitou Islands, and 12 miles SE of Manistique.

Although the Wisconsin fishermen sent in five lake trout in 1947 which on the basis of size (8¾ to 12½ inches) and age (2½ to 3½ years) could be fin-clipped hatchery fish, they must nevertheless be classified as doubtful because of the great distances involved between the points of capture and release and the isolated or discontinuous nature of the records of capture. The five specimens were taken at widely separated localities: Washington Island (1), Algoma (2), and Racine (2). Available information indicates that small baby trout rarely travel such great distances. Further, those off northern Lake Michigan seldom enter depths greater than 50 fathoms (in Michigan marked baby trout were recovered in 8 to 35 fathoms in 1947, 10 to 45 (2 in 60) in 1948, and 6 to 55 (2 in 60) in 1949. They must then follow the shallower water in order to reach Wisconsin territory, unless they cross the lake swimming high (which is not probable). If such an inshore migration had taken place then the Michigan recoveries in 1947 should have extended over a much wider area in northern Lake Michigan such as occurred in 1948 and 1949.

In 1948 all Michigan recoveries were made in the area enclosed by a line roughly drawn from Pyramid Point to South Manitou Island to South Fox Island to Gull Island to Manistique. Specimens recorded from Michigan localities outside this area

Table I—Recoveries of Fin-Clipped Lake Trout from Lake Michigan, 1947-1949

Year of Recov'y	Item	YEAR OF FIN-CLIPPING AND PLANTING									
		STATE OF MICHIGAN					STATE OF WISCONSIN				
		1944	1945	1946	Doubtful	Total	1944	1945	1946	Doubtful	Total
1947	Number	8	32	0	43	83	0	0	0	25	25
	Length (in.)	11.6	10.1	—	—	—	—	—	—	—	—
1948	Number	10	207	9	62	288	0	0	0	14	14
	Length (in.)	14.6	12.8	10.0	—	—	—	—	—	—	—
1949	Number	17	570	59	49	695	0	93	2	12	107
	Length (in.)	15.3	14.2	12.3	—	—	—	13.1 (92)	10.8	—	—
Total	Number	35	809	68	154	1,066	0	93	2	51	146

were too large to be considered fin-clipped fish except 17 baby trout taken at South Haven and 1 at Benton Harbor. The isolated or discontinuous nature of these southern records, their lack of adherence to the lake trout dispersal pattern, and the fact that 47 per cent (8 fish) of the trout had abnormal left pectorals (1946 mark) in contrast to only 4 per cent (9 fish) with such a mark in the area of release throw grave doubt on the authenticity of these returns as hatchery fish. The acceptable 1948 recoveries indicate, then, that the young lake trout had moved southward along the Michigan shore to Pyramid Point and spread northward towards the reefs off Epoufette and Naubinway and northwestward towards Manistique. The 15 Manistique specimens were all taken on various dates in one spot, 11-13 miles southeastward of the port, and there were no 1946 year-class fish among them (1944-2; 1945-13).

Wisconsin fishermen sent in seven baby trout in 1948 which on the basis of size and age could qualify as fin-clipped hatchery fish. They came from the following localities: Sturgeon Bay (4), Two Rivers (2), Racine (1). These scattered Wisconsin records are, however, open to the same serious question as those of 1947, and they have therefore been classified here as doubtful.

In 1949 the marked trout again extended their range considerably in Michigan moving farther southward along the shore down to Pentwater and southwestward from Manistique to the islands (Big Summer, Poverty, and Gull Island) at the entrance to Green Bay where 40 recoveries were made. The only port where baby trout with abnormal fins were taken south of Pentwater was South Haven, and of the 19 specimens 74 per cent (14 fish) showed the 1946 mark in contrast to the more northerly waters where only 9 per cent of 631 fish showed this mark. (Out of 228 recoveries made off Manistique and Fayette only 5 per cent (11 fish) showed the 1946 mark). These contrasts as well as the isolation again make the South Haven records doubtful the same as in 1948.

In further explanation it may be noted that it is difficult to believe that nearly as many or more fish of the less available 1946 year class than of the more available 1945 group had moved southward out of the area of release in 1948 and 1949 and that they had managed to avoid the commercial nets on their migration until they reached South Haven. Further, it will be shown later that baby trout normally disperse in a continuous and gradual manner (not by big jumps) from the area of release. It will also be pointed out later that trout with the 1946 mark did not enter commercial nets or move out of the area of release in numbers until the last two months of 1949 and the first two of 1950. It would seem, therefore, that the 1946 marked fish had not been in the lake long enough to reach South Haven in 1948 and 1949 in such relatively large numbers as was indicated.

As was true in 1948 so also in 1949 all of the Manistique specimens, 188 in number, were taken southeastward of the port in the same general region. It is of interest to note also that the Manistique fish represented 29 per cent of the Michigan recoveries in 1949 as compared with 7 per cent in 1948—a distinct movement of clipped trout towards the west (as well as south) took place in the State of Michigan in 1949 extending to Green Bay.

This statement is supported by 95 Wisconsin records for 1949 which show that fin-clipped baby trout migrated beyond the Michigan recoveries to the south as far as Ellison Bay in Green Bay and Sturgeon Bay canal in Lake Michigan. The 12 Wisconsin trout classified as doubtful were taken in or off Rowley Bay (1), Cana Island (2), Sturgeon Bay (1), Two Rivers (3), Cedar Grove (4), and Racine (1). Only 2 per cent (2 fish) of the 95 fin-clipped trout belonged to the 1946 year class; all others were 1945 fish.

The data indicate that the fin-clipped lake trout spread gradually in all directions from the points of release being restricted, however, by deep water. Dispersion seemed to have been than 55 fathoms) as is evidenced by confined to the shallower waters (less the depths at which nearly all specimens were recovered. By the end of 1949 the movement had extended southward along the Michigan shore to Pentwater, northward to the reefs off Epoufette (no recoveries in Straits of Mackinac or Lake Huron), and northwestward toward Manistique continuing southwestward along the Wisconsin shore to Sturgeon Bay canal and in Green Bay to Ellison Bay. The distribution now seems to have assumed a horseshoe pattern with the points projecting southward, one along each shore. The further extension of the two points will no doubt depend on the available stock of 1945 and 1946 marked fish.

As already indicated the 1944 clipped trout stocked in the lake failed to survive in large numbers. Virtually all of the recovered fin-clipped fish belonged to the 1945 year class. Not until 1949 did the 1946 planting show up in any numbers and then almost entirely in Michigan waters where 62 per cent (34 fish) were recovered in the area of release. In fact, it was not until the end of the year (November-December) that the recoveries of 1946 marked fish exceeded those of the 1945.

That the 1946 year class had just begun to enter the commercial nets and to move from the area of release in numbers is further evident from the recoveries made in 1950. In January and February 1950, Michigan fishermen sent in 46 clipped trout of which 20 (44 per cent) were marked in 1946 and the remainder in 1945. Of these 20 fish, 40 per cent were captured outside the area of release 12 to 14 miles southeastward of Manistique. The Wisconsin fishermen sent in 11 clipped trout in 1950— 4 in January and 7 in the first half of February. Four (36 per cent) were marked in 1946 and seven in 1945. None of the 1950 records has so far extended the range of the marked trout beyond that reached in 1949.

That dispersal of baby trout was a gradual and progressive process is further indicated by the following State of Michigan data which show a decided correlation between the approximate length of time the fish had been released and the percentage of recoveries made outside the area of release.

The longer the trout of a year class were in the lake the greater the number and percentage that had moved out of the area of release. This statement applies to all three classes involved (1944-45-46).

Length of Time Out in Years	—1	1+	2+	3+	4+
Per Cent of Recoveries in Outside Areas	0	3	23	52	70

4. Gillnets with $4\frac{1}{2}$-inch mesh or larger took 95 per cent of the State of Michigan recaptures in 1947, some 82 per cent in 1948, and 44 per cent in 1949. The remaining specimens were caught in $2\frac{1}{2}$-inch-mesh gillnets. The progressive decrease in the relative catch of the big-meshed nets was the result of the movement of marked trout into deeper water. The big-mesh nets were nearly all (93 per cent) lift-

ed from depths less than 26 fathoms (average 19) whereas only 49 per cent of the small-mesh nets were set in these waters (average depth set 28 fathoms). Contrary to expectations, the marked trout taken in the deeper waters (26 fathoms or more) averaged slightly less (13.2 inches) than those caught in the shallower water (13.7 inches), and the specimens taken in both types of nets averaged exactly the same (13.6 inches).

5. The occurrence of deformed or missing fins in nature is not uncommon although only a small percentage of wild fish show such abnormalities. Out of 1,321 trout (including 203 baby fish) examined in 1947 from southern Lake Michigan only 3 fish (0.22 per cent) had deformed fins. Similarly in 1948 out of 1,462 Lake Superior fish 3 (0.20 per cent) had abnormal fins. Wisconsin investigators reported 4 trout (0.17 per cent) with fin abnormalities out of 2,311 inspected in 1947 at Milwaukee, and during the fin-clipping in 1948 only 1 fingerling trout of 22,665 was observed with a missing fin (pelvic); 104 had three pelvic fins. Minnesota investigators examined 14,919 pounds (about 2,000 fish) of marketable trout at Duluth in October 1949, but found no fish with deformed fins.

6. Only scant information is available on the ratio of marked hatchery trout and unmarked baby trout in the commercial lifts made in or near the areas of release. Inspection of gill-net lifts in May 1949, revealed that 14 (13.3 per cent) out of 105 baby trout examined at Charlevoix, Michigan, were fin-clipped, and none of the 230 baby trout examined at Frankfort, Michigan, were marked.

7. Growths in total length and round weight as determined from State of Michigan trout recovered during the period, September or October-April, were as follows (the average lengths of the weighed fish never varied more than 0.1 inch from those shown in table A.)

Data of fish of the same age group but of different year classes were combined. Only specimens recovered in the fall and winter months were used except those of age-group V which were captured in May-July, 1949, (none taken later). The data of groups II-IV, then, actually represent growths of almost one more year than is indicated by the roman numerals. Thus the 11.2 inches of group II really represent three full summer's growth, that is, the approximate length of fish exactly 3 years old, assuming no growth occurs in winter. Data were selected in this manner to avoid errors that presumably would result from the progressive change in growth during the summer months. Errors due to mesh selectivity or non-random sampling of fish ensnarled or "mouthed" in gill nets have not been eliminated.

The Wisconsin records of length and weight were not combined with those of Michigan since a comparison of the monthly averages of lengths of the large 1945 year class revealed that the trout recovered in Michigan consistently ran larger than those of the same age retrieved in Wisconsin. The data likewise indicated that peculiarly enough the average lengths did not change significantly in any one direction during the period, January-August, 1949, but did increase in the months, September 1949 - January 1950, although no progressive change occurred within this period. These facts are illustrated in part in table B.

8. After 1½ years 90 to 97 per cent of the 1944-45-46 and 64 per cent of the 1947 marked trout that survived in experimental ponds were still recognizable (regeneration of fin, if any, one-half or less). Complete regeneration occurred in only 1 to 5 per cent of the former group and no growth in 43 to 79 per cent whereas at least 16 per cent showed complete regeneration and 9 per cent no growth in the latter group.

9. The difference in the recorded percentages of mortality (which was consistently less in the controls) between fin-clipped and unmarked trout in the experimental ponds decreased progressively with increased age from 8.3 per cent 1 1/12 years after the clipping in the 1947 year class to 2 per cent after 4 1/12 years in the 1944 class. The difference was 7.1 per cent after 2 1/12 years in the 1946 fish and 5.1 per cent after 2 2/3 years in the 1945 marked trout. However, since a certain percentage of the marked fish regenerated completely the excised fin (and would therefore have been classified as unmarked controls), the differential mortality must actually have been less than indicated.

10. No significant or consistent difference existed in the growth of the clipped and non-clipped trout of the same age in the experimental ponds. It is of interest to compare the approximate average lengths and weights of these pond-reared fish at various ages, as shown in table C. Their growth corresponded very closely with that of the recovered trout (see item 7).

11. Experiments on the differential

TABLE A

Age group * 1	II	III	IV	V *2
Total length (in.)	11.2 (29)	14.4 (131)	15.5 (44)	14.8 (11)
Weight (oz.)	6.5 (24)	14.2 (108)	17.4 (37)	15.0 (6)
Increments-length	. . .	3.2	1.1	. . .
Increments-weight	. . .	7.7	3.2	. . .

* 1—*Numbers of fish are shown in parenthesis.*

* 2—*Recovered May-July,* 1949. *All other fish were taken during the period, October-April, except the* IV *group which was taken during September-April.*

TABLE B

Date	MICHIGAN		WISCONSIN	
	Number of fish	Average length (inches)	Number of fish	Average length (inches)
Jan.-April, 1949	91	14.6	58	12.9
May-August, 1949	442	14.0	34	13.3
Jan.-August, 1949	533	14.1	92	13.1
Sept. 1949-Jan. 1950	35	15.7	—	——

TABLE C

Approximate age (years)	Length (inches)	Weight (ounces)
1½	6.8	1.5
2½	10.2	5.0
3 1/12	11.6	7.8
4½	16.6	22.3

mortality of marked and unmarked trout in the presence of predators were completed in 1949 but the final results are not yet available. There is, however, clear-cut evidence that mortality among both groups was considerably reduced where underwater cover was available.

12. Biological data and scales were collected from thousands of lake trout on Lakes Michigan and Superior. Preliminary analysis indicate that the scales can be employed for age determination.

This statement is supported by the data of Table II which presents the average total lengths and weights at capture and the estimated lengths from scale measurements for each year of life of all lake trout taken in one gang of gill nets lifted off Montague, Michigan, on October 1, 1947, (readings and estimates by Dr. F. W. Jobes). Since the males and females showed no consistent differences in their average growth rates, which were nearly the same, the data for both sexes were combined in the table. The computed lengths for any single year of life agree remarkably well for fish of the different age groups (II, III, IV, etc.) in spite of the relatively small numbers of specimens employed. This fact and the good agreement between the actual lengths at capture (third column) and the calculated lengths (bottom of table) of fish at approximately corresponding ages give strong evidence that the ages assigned are correct.

Lake Huron

13. In September 1947 and 1948, some 510,647 lake trout fingerlings were planted off Alpena, Michigan, of which 73,890 (14.5 per cent) were fin-clipped as shown in table D. No returns have been received.

14. In 1947 Ontario clipped the fatty fin from 500 wild trout about 4 to 7 years old and released them in South Bay, Manitoulin Island. Similarly in 1948 and 1949 several thousand additional wild trout about 12 inches and larger were fin-clipped and/or tagged and released in this bay.

TABLE II—Average total lengths (inches) and weights (pounds and ounces) at capture and calculated lengths of 97 lake trout taken off Montague, Michigan, October 1, 1947 (sexes combined).

Age Group	Number of Fish	Length at Capture	Weight at Capture	Calculated Length from Scales at End of Year of Life								
				1	2	3	4	5	6	7	8	9
II	2	9.2	0-3	4.4	6.9							
III	12	12.5	0-9.3	3.9	7.8	10.4						
IV	4	16.6	1-8.5	4.6	8.4	11.6	14.7					
V	17	20.7	3-0.4	4.9	8.6	12.2	15.4	18.4				
VI	30	23.1	4-4.3	5.1	9.0	12.4	15.7	18.7	21.3			
VII	25	24.6	4-14.5	5.2	8.4	11.7	15.1	18.3	21.0	23.1		
VIII	6	25.2	5-10.7	5.0	8.6	11.8	14.8	17.6	20.1	22.6	24.2	
IX	1	28.9	10-0	4.5	10.3	13.4	16.2	19.9	23.0	24.9	26.6	28.0
Average		21.4	3-11.3	4.9	8.5	11.9	15.4	18.4	21.1	23.1	24.5	28.0
Increments				4.9	3.6	3.4	3.5	3.0	2.7	2.0	1.4	3.5

TABLE D

Year	Fin removed	Number clipped	Per cent of total planted	Average length (inches)
1947	right belly (pelvic)	51,284	15.1	2.9
1948	left belly	22,606	13.2	2.8

Lake Superior

15. In 1946-48 Ontario fin-clipped 74,543 lake trout and planted them inshore in Lake Superior in the area below Nipigon Bay and the entrance to Black Bay, Ontario, as follows:

1946—Fatty fin removed from 4,500 yearlings (1945 year class);

1947—Left front (pectoral) and fatty fins removed from 10,000 yearlings (1946 year class);

1947—Fatty fin removed from 27,574 fingerlings (1947 year class);

1948—Left front and fatty fins removed from 32,469 fingerlings (1948 year class).

16. Forty-seven recoveries were made in 1947—49 from depths of 5 to 30 fathoms in the area of release—off Rossport, and Wilson and Salter Islands, in Simpson Channel, in Moffat Strait, off south shore of St. Ignace Island, and Fluor, Puff, and Lamb Islands. Thirty-eight (81 per cent) of these fish belonged to the 1945 year class and 9 to the 1946. Of the former, 6 were taken in 1947, 17 in 1948, and 15 in 1949; of the latter, 4 were captured in 1948 and 5 in 1949. In addition 7 doubtful, non-verified recoveries were reported in 1949. Thirteen fish of the 1945 brood recovered in 1949 (4½ years) averaged 13.3 inches in length and 10.5 ounces in weight.

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ON INCREASING THE EXPLOITATION OF AQUATIC RESOURCES FOR WORLD FOOD NEEDS

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(*Read October 26, 1950, by E. H. Dahlgren, Chief Section of Marine Fisheries, Fish and Wildlife Service, in the Symposium on Scientific Possibilities for Increasing the World's Food Supply*)

It is difficult for meat-eating people like Americans to think seriously about fish as an important article of diet, for the use of fish which most touches our sentiments is recreation. Yet there are countries where people think with dead seriousness about a handful of minnows, not as bait, but as the only flesh they will have for several days to balance their monotonous vegetable fare. As our population grows, we, too, will find fish becoming more and more important in our diet. Therefore, it is important not merely for the distressed countries, but for us, too, to consider how the production of fish might be increased.

Let us begin by agreeing to a few simple statements which are widely accepted as fact:

Everywhere in the world there are people whose physical well-being is below its potential for want of optimal quantity and quality of food.

More than half the people in the world are densely concentrated in areas where the average food supply is far short of being optimal.

Animal protein foods are nutritionally important because of their high "biological value" and their high content of vitamins and minerals. But it takes so much land and costly feeding to produce meat, milk, cheese, poultry, and eggs, as to push such foods far beyond the reach of people living under the pressures of poverty. Therefore, if it is at all possible to produce cheap animal protein in usefully large quantities, the most likely source of it is the food organisms living in water, mostly fish.

In the ocean, many fishery stocks have long been exploited to their fullest productivity (some of them far beyond that point); nevertheless, there remain other, quite primeval stocks of fishes living in the ocean for the taking. In inland areas, particularly in the so-called "backward" countries, fish farming is a very old art; nevertheless it could be expanded wherever there is enough water, even in those countries where it has been longest established and where it is most highly developed.

These potentialities, the untouched or underdeveloped ocean fishery stocks, and the inland areas that could be developed for fish farming, are not distributed uniformly over the earth, nor are they concentrated in any convenient relation to the populations that need them most, or to centers of skilled labor capable of exploiting them. So long as they remain mere potentialities they are of no direct service to human needs. If and when they do finally become exploited, their value will be proportional to the volume and cost of food which they yield. They will be of little importance unless they yield very large volumes very cheaply. This requires the kind of organization which is called *a fishery*, which means a stock of fish, skilled fishermen (or fish farmers), and the complex system of industries—boat building, net and twine manufacturing, preserving, transporting, marketing, and so on, without which the great fisheries cannot exist.

The question which I propose now to explore is this: What problems must be faced and solved in order to generate and develop fisheries in the "backward" countries? Here we need a definition. What is "backward"? There is much preoccupation among humanitarian people today about the inequalities in standard of living between those few populations that are very well fed, and those many populations that live in a way that we North Americans would describe as being intolerably close to destitution and starvation. We describe the one type of population as "backward," and the other as "advanced." But backwardness is not a quantity that can be measured objectively. To us well-fed, industrial-minded people, brought up in a tradition of physical well-being, backwardness is utterly foreign to what Orientals, for example, would associate with the term (if they thought about it at all), living in their ancient

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cultures that center around the spirit rather than the flesh. Therefore, for the purposes of this discussion, I will restrict the phrase "backward country" to mean one in which the per caput supply of food is remarkably below optimal biological needs, and where potential food resources could be utilized by the application of appropriate technological effort.

To start this effort is to generate a revolution in custom, a really formidable task. For this it takes men who are genuinely interested, clear-thinking, technically capable, practical-minded, and willing to work actively towards a goal which may be many generations away. At present, the number of available men is very small; in the "advanced" countries, there are certain nuclei of such men, humanitarian and international-minded, who are professionally consecrated to the end of raising the standard of living in the depressed areas. Among these, the number concerned with fisheries development is a small minority even though the fisheries may be the most promising hope of producing cheap animal protein. For example, in the Food and Agriculture Organization of the United Nations, there are no more than twenty men in the Fishery Division; twenty men to introduce new fishery industries, new techniques of fishing and of fish farming all over the world, not to mention changing dietary habits of whole populations! In the "backward" countries there are also a few nuclei of men, who are humanitarian, who have travelled widely, and would like to change the living condition of their compatriots. But the number of those in a position to lead, to be articulate about their hopes, and able technically to transform it to a course of action, is pitifully small. So here is the situation at the outset: a handful of people arrayed against a complex of opposing forces, of which perhaps the greatest is the very magnitude of the number of people they are striving to affect.

The obvious ready answer to this problem is "Education." Hasn't that been successful in countries like North America? Hasn't education (or is the word "advertising"?) taught our producers to improve agricultural methods, and consumers to select and demand balanced diets properly loaded with the whole gamut of vitamins? Doesn't our government issue a remarkable assortment of pamphlets for those purposes? The United States Fish and Wildlife Service, for example, publishes one quarterly journal for fishermen and fish handlers in order to give them technical information on how to improve their methods and another quarterly journal for fish culturists dealing with hatchery practices and fish farming. Why not spread that kind of service everywhere?

But in the "backward" countries the man who needs education to produce more food, the person with whom we are concerned today, is illiterate; he cannot read. If he lives in a rural area, he has never seen a radio nor heard one. His only communication is by word-of-mouth. He is not likely to listen to a speech, or to attend anything like a series of classes, even though they be free. If one is to educate him he must begin with very small groups, perhaps of only three or four. From our point of view, his life is hemmed in from every direction by centuries of tradition; and he will sacrifice any material utility for the sake of the mental comfort which his tradition provides. He is filled with mysterious prejudices, is suspicious of the unorthodox, of novelties, of strangers, and of his own government. If 2,000 calories a day is his optimal biological requirement of food, he gets, *on the average*, only a quarter that amount; but his food supply fluctuates widely around that average so that sometimes he has plenty, sometimes nothing and then he must migrate in search of food, or die. He suffers from chronic deficiency diseases, and from various infections to which his condition has made him susceptible. Sometimes, by our standards, he is lazy. He has no money. He does not think of himself tragically as being badly off unless he is actually starving under a famine. Finally, there is almost infinite variation in all these conditions from one country to another, so that no universal formula can be devised for improving the lot of such people according to our standards.

It goes without saying, then, that a fishery technician having the problem of introducing to an unknown people a new way of producing food, perhaps to them a new kind of food, will meet many resistances. He can begin his task only by invitation of the government of the country in question; for of course a technician cannot push his way into a place uninvited. But the government must do more than merely invite him. It must be *actively* interested in the success of his enterprise. It must be ready to organize and finance a fishery administration for the purpose of fostering fisheries, not for the purpose of merely making more governmental jobs. It must provide whatever facilities are needed. For fish farming, that means land and labor for construction of the installations. Most of all, the government must continue to support the project permanently, which means it must be so stable that the project will continue in spite of political changes.

Supposing a government has all those desired qualities and has invited a technician to introduce fish farming. Suppose the technician finds on surveying the country that there is ample space for constructing ponds, that the water supply is adequate, and that conditions look promising for pond culture development. What then? Then those sponsoring the technician must resist every temptation, every pressure, to attempt developing the project on a grand scale. The technician has so much to learn himself about the country, the climate, the fauna, the ways and tastes of the people, so many things can go wrong to destroy the whole project, that it is not merely the best thing to do, but it is absolutely essential, to begin the project on a very modest and tentative scale. Two or three local people will be plenty to work with the technician at the start. These he will recruit from among the educated class, and that in itself will take time, for not all educated people whom he interviews will be interested in fishery work or suited to it. When at last he does find promising men, he has the job of training them to take over the fishery administration and the responsibility of continuing the growth of the project after he leaves it.

Here, incidentally, arises a special cultural problem for the technician. Education is a necessary qualification of his newly-found associates. Besides making them literate, it has taught them to think systematically and has advanced them beyond the limitations of folk prejudices. But it has its unfavorable side, for it has given them other sorts of prejudices. Those in the "backward" countries lucky enough to go away for education tend to lose touch with their compatriots. They return conditioned to the foreign country where they studied; they have developed a taste for the culture of cities; they want white collar work; they eschew association with their less favored compatriots; they have withdrawn from the soil. It is the sort of thing that happens in the United States, too, but not to such an extreme degree. So it is that after the fishery technician has recruited the educated men who are to be the backbone of his project, he often must re-educate them to do the kind of dirty work that goes with fish culture. This may take a good deal of time, and patience.

If the little team thus formed is very lucky, it will succeed during its first year in establishing a demonstration center with about ten ponds and a small laboratory and fish nursery. The expenses for the purchase of land, the construction and salaries of the staff can be of the order of $20,000 for the first year. In subsequent years, small groups of carefully selected farmers will be brought to this demonstration center for short periods of training to set up ponds of their own; and gradually other demonstration centers will be established throughout the country. Appreciable results in the form of large production of fish should not be expected for several years. "Pouring in" money cannot speed the process. Success will depend on a happy combination of many circumstances—luck, the sincerity, ingenuity, and aggressiveness of those engaged in the project, the stability of the government, and adequate concomitant development of preserving, transporting, and marketing facilities, and a willingness of the public to eat the fish. The possible rewards are impressive. Dr. S. Y. Lin, of F.A.O. estimates a possible increase in the production of fish by pond culture in several countries as shown in table 1.[1]

TABLE 1

Country	Population in thousands	Estimated potential area for new pond development (thousands of acres)	Estimated yield in thousands of tons
China	420,000	3,700	4,150
India	337,000	2,471	660
Indo-China	25,000	1,235	914
Indonesia	76,000	1,235	338
Japan	80,000	247	57
Malaya	4,000	247	220
Philippine Islands	19,960	1,235	196
Thailand	17,000	247	220

The fishery administration set up for pond fish culture can, in some areas, also foster a fuller use of rice paddies for fish farming. This method depends on the fact that rice culture requires flooding the fields for periods of three to six months each year. By planting fry at the beginning of a flood period, a farmer can harvest a crop of fish at the end which have grown and fattened on the nourishment furnished by the rotting rice stubble, The method depends on the development of a nursery fry industry, which can be closely associated with farm ponds.

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[1] Unpublished MS.

How much extra food might be produced thus we do not know. In some countries, rice paddy fish culture might be already pretty fully developed; but in other countries it could ultimately be extended to produce very large quantities of fish. But here again the development would be impeded by a multiplicity of obstacles, and would take a long period of time.

It is true enough that the cultivation of fish in fresh waters, whether in artificial ponds, in rice paddies, in impoundments back of dams, or in irrigation ditches, can in the course of sufficient time be a most fruitful way of improving the supply of protein food. But this is by methods of long standing conventionality, and may prove disappointing to people who want something more heroic. If we may judge by articles frequently appearing in the magazines and newspapers, what people expect now is more miracles of Science, say an entirely new kind of food that can be produced in massive quantities at negligible cost, which somebody will eat, presumably the backward peoples. If anything so novel could be taken from among the aquatic resources, it would more likely be found in the ocean than in the fresh waters. For in the ocean there is an unknown thing, still unexploited, still unexplored, which may prove to be an extravagantly large food resource. This unknown thing scientists refer to as the "Deep Scattering Layer."

During the Second World War, technologically improved echo sounding instruments disclosed the presence of a layer of something between the bottom and surface, which produces an echo. This layer seems to occur everywhere in the ocean. It moves diurnally, toward the surface about sunrise and sunset, away from the surface during the intervening times. Hilary Moore (unpublished MS. 1950) says,

> Most often there is only a single layer, but on a number of occasions, two or more distinct layers have been recorded, and there is little doubt that improved techniques will allow the separation of such multiple layers more regularly in the future. There may also be layers which do not execute the same type of diurnal migration as the main layers. Finally there is often a very deep layer lying at a depth of about five hundred fathoms, and this may execute a diurnal migration. [See fig. 1.]

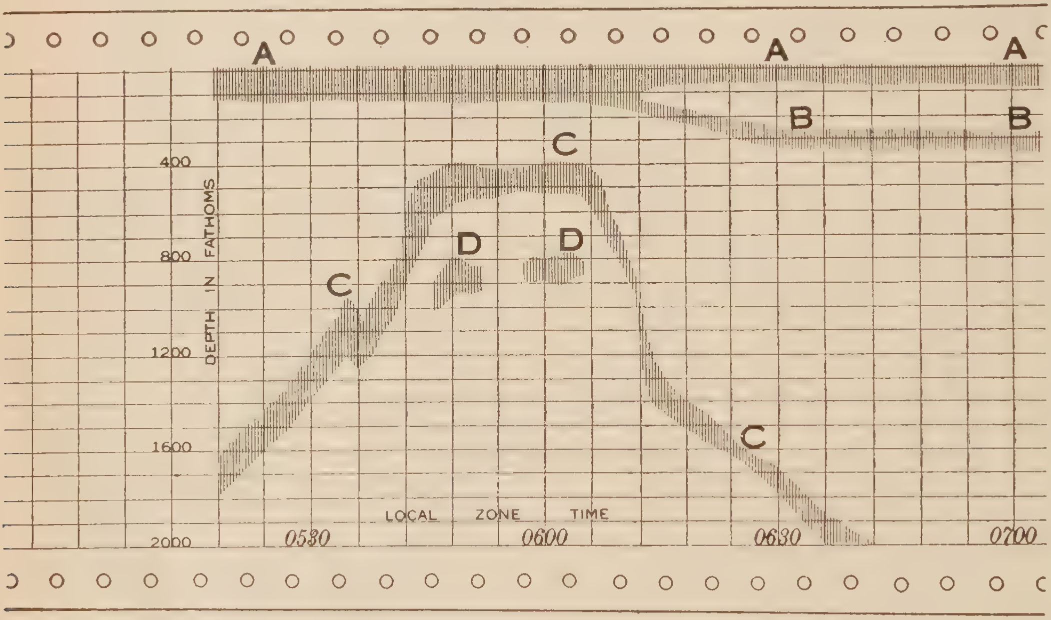

FIG. 1. Line drawing made from a fathogram to illustrate scattering layer.

A. Record of outgoing signal.
B. Record of scattering signal.
C. Bottom.
D. Double echos produced at twice actual depth.

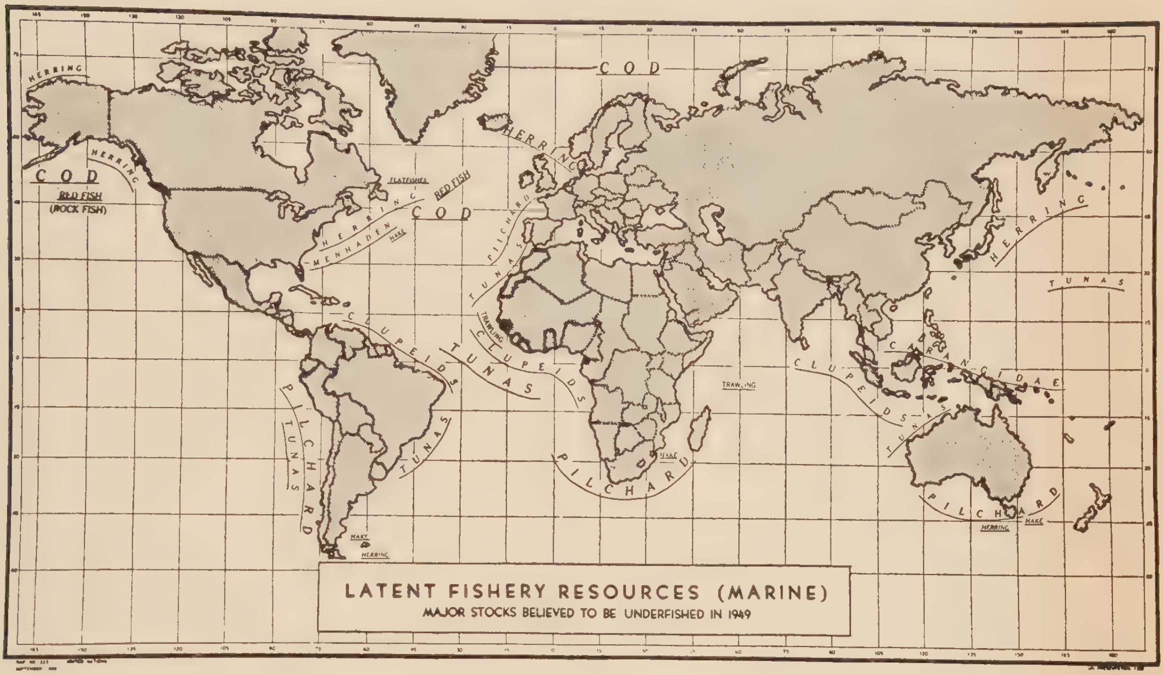

FIG. 2.

Everyone who has studied this phenomenon agrees that it is caused by masses of living organisms. However, the technical problems of determining the composition of these masses are formidable, for it is mechanically difficult to hold nets down to the depths where the layers occur and operate them there. Moreover, the resistance of the water against wire and nets at those depths so depresses towing speeds that any significantly sized organisms could easily elude ordinary fishing gear. Consequently, the composition of the scattering layers remains unknown. Oceanographers vary in opinion as to what composes them; and until they have solved the technical fishing problems they can do no more than speculate as to whether the dominating fauna be fish, squid, prawns, euphausids, copepods, or something still unnamed. Whatever it be, if it is abundant enough and useful enough to be worth exploiting, methods of large-scale fishing would have to be invented resembling nothing with which commercial fishermen have ever had experience. Commercial fishermen are unlikely to invent anything so novel in the foreseeable future. They tend to be conservative. Their techniques advance very slowly in small steps; and they are generally loath to stray far from the areas or the methods which they have found productive enough. They have always exploited only the layers about the bottom and near the surface and in the places which they know intimately. Possibilities of commercial profit in the deep scattering layers are much too uncertain to justify commercial fishermen gambling their money or time to explore it, not to mention the investment it would take to develop some use for whatever they might find.

So far the governments of the "advanced" countries have been too preoccupied with studying the well-established fisheries for conservation purposes to use their very limited research facilities for exploring anything so uncertain as the deep scattering layers. The F.A.O. is unable to undertake such a project, for it has no vessel or any other research facilities. There remains only universities and private research institutions, but at present the exploration of the biological composition of these mysterious layers must await enough money—perhaps something of the order of $100,000—to finance the development of appropriate gear and the operation of a suitable experimental vessel.

The least result to be expected from such a research into the deep scattering layer would be the extension of human knowledge about the earth; the most valuable practical result might be undreamed of quantities of food. Surely either possibility is worth striving for on an international scale.

Meanwhile, the more familiar resources must be pursued.

We are quite certain that several stocks of ordinary kinds of ocean fishes like cod, herring, sardines, and tunas, are under-fished; and among them are probably virgin stocks not yet touched.

A little over a year ago at Lake Success, the United Nations sponsored a Scientific Conference on the Conservation and Utilization of Resources. There, several fishery experts pooled their information to draw up a chart showing where they believed latent fishery resources to be located; as a minimum estimate, these might yield a minimum increase of about four million tons, which is around 22 per cent of pre-war production (Thompson, 1949). Of this amount perhaps 2.7 million tons could be expected from cold and temperate waters, and about 1.3 million tons from tropical and subtropical waters. (See fig. 2.)

As I said earlier, however, a fishery is a complex organism comprising fish, equipment, and men. It cannot spring into being full grown. It cannot even start developing unless there is a hospitable atmosphere for its growth. The rate of growth of a fishery will depend largely on the development of supporting industries. Wherever a fishery exploits a stock of fish to its fullest capacity or, in other words, has become mature, it has reached that point thanks to a sufficiently large fleet of vessels with skilled fishermen, and adequate vessel building and repairing facilities, harborage and means of keeping the harbors in good order, wharves, machine shops, fuel tenders, freezers, salteries, canneries, net and twine manufacturers, and dealers of all sorts of miscellaneous articles incident to the operation of boats and shore plants. Developing fisheries follow a logistic growth curve such as characterizes the growth of animals, of populations, and of industries that depend upon populations. Under the most favorable conditions it takes several years for a fishery to mature. For example, the pilchard fishery on the Pacific coast of the United States took about twenty-five years to grow from its inception to the point where its yield began to fluctuate around an asymptote of 550,000 tons a year (Schaefer, Sette and Marr, 1950)[2] (see fig. 3). At that point the capital investment in vessels and fishing equipment was perhaps of the order of $17,000,000 in terms of the 1942 value of the dollar. There were 3,039 men engaged primarily in pilchard fishing, and 280 vessels; 38 canneries were in operation for canning pilchards, and 71 factories for manufacturing pilchards into fish meal and oil. The total capital investment in these factories was perhaps something of the order of $60,000,000.[3]

Thus the Pacific pilchard industry, which grew under fairly auspicious circumstances, occupied twenty-five years in the growing and involved a capital investment for boats, gear, and factories of *roughly* 77 million dollars to produce an average annual catch of around 550,000 tons. These figures give a general idea of what is required for the development of a great oceanic fishery.

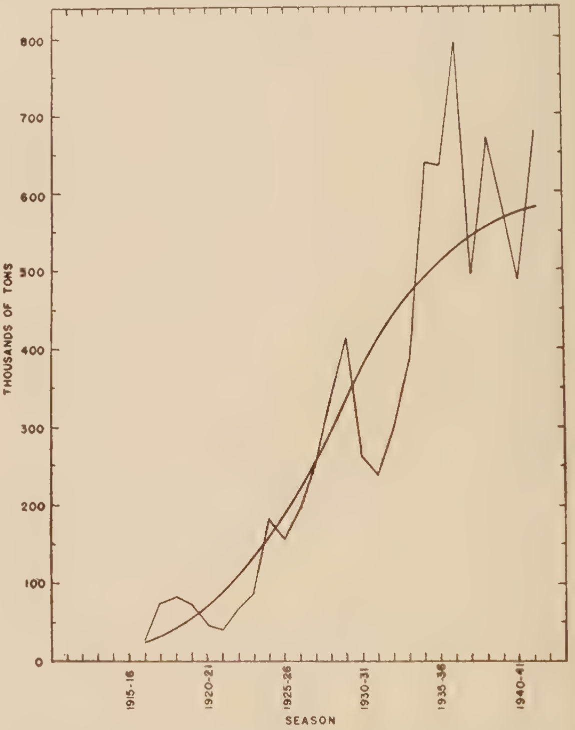

FIG. 3. Total catch of pilchard on the Pacific Coast and fitted trend for the period 1916–17 to 1940–41.

The capital investment required varies widely among different types of fisheries and among different areas, as Richard Kahn has shown in these estimates (table 2).

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[2] The non-random, short term fluctuations over the course of this growth curve are closely related to fluctuations in economic conditions.

[3] These figures are based on material furnished by Dr. Richard A. Kahn, Economist, Fish and Wildlife Service.

TABLE 2

Area	Capital investment	Capital investment per fisherman	Tons of fish caught
Washington	$63,638,924	$3,326	98,000
British Columbia	30,913,279	2,528	307,000
Ontario	5,716,075	1,500	15,000
Nova Scotia	15,097,992	1,012	188,000
Manitoba	2,442,628	360	16,000
Northwest territories	292,000	730	4,000
Texas	7,883,000	2,320	28,000
Ceylon	8,775,000	195	40,000
Puerto Rico	458,640	172	2,000

The growth rate of a fishery like any organic growth appears to be a property inherent in the constitution of the organism. It depends on the magnitude of the fish stock, the size of the population of the people utilizing it, the degree of their technical advancement, the amount of capital that can be drawn upon to feed the industry, and a complex of other interrelated elements.

In my opinion the most significant thing people can do to increase the production of aquatic resources for contributing to the world's food needs is to stimulate the inception of new fisheries. Beyond that they might be able to speed up the rate of growth of those fisheries, but only within the rather narrow bounds of the inherent potentiality of each situation. To start a marine fishery involves for the technician about the same kind of sociological, economic, and political problems that he must deal with in starting a pond fish project. The resistances and the prejudices he faces might be different, but they will have the same impeding effect. We should, therefore, not be discouraged if results are slow in appearing. For we are dealing in processes which may run over the course of many generations; but whatever our generation can contribute, no matter how trifling, will make its mark.

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SCIENTIFIC AMERICAN

V. 185: 27-28

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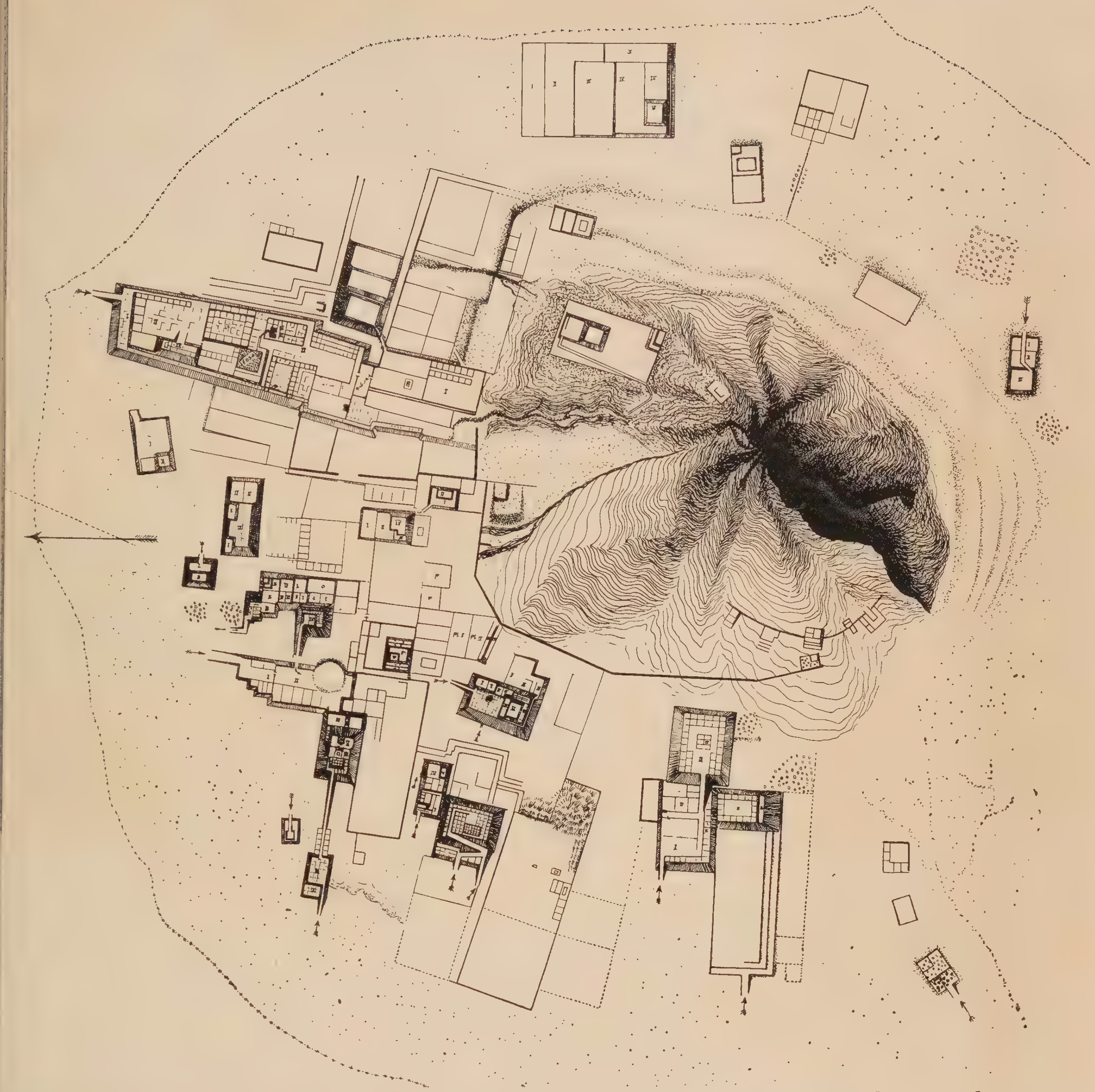


DRAWING OF EL PURGATORIO is a partial reconstruction based on ground surveys and the aerial photograph on the opposite page. The elevated structures of El Purgatorio were built with an eye to defense.

ginnings of city life. And here in coastal Peru we had an unusual opportunity to study how cities began, for the sites of the towns and of the metropolises that came later stand side by side, whereas in the Old World the former are buried beneath the latter. Thus from the data revealed by the aerial photographs we could work out the origin and development of city life in more detail in Peru than anywhere else in the world.

On the basis of these photographs and first-hand reconnaissance at the sites we have been able to draw ground plans of some of the town sites. One of these is illustrated in the photograph and drawing above. This town, called El Purgatorio, is built around a large natural hill in the center of the well-watered plain of the Leche Valley. The main buildings, dating from the "middle period," are clustered at the north end. These large pyramids with numerous room divisions are transitional building types between the solid pyramids of the earlier Mochica period and the later truly urban compounds, in which all the building space was given to rooms. It is likely that they were palaces housing several families of the ruling class, along with servants and craftsmen. At the southern and southwestern sides of the ruin are remains of what appear to be old pyramid complexes.

Until the last decade the quantity, size and complexity of ancient Peruvian towns and cities could only be guessed at. Aerial photography has made it possible for us to comprehend them for the first time in their large-scale significance. Let us hope that the sandy mantle that has covered them for centuries will be lifted soon to reveal the internal functioning of these thriving metropolises of prehistoric Peru.

Richard P. Schaedel was director of the Institute of Anthropology at the University of Trujillo in Peru from 1948 to 1950.

V.183 : 24-28.

THE DEEP-SEA LAYER OF LIFE

Hundreds of fathoms down in the oceans is a drifting mass that once was called the "false bottom" but now is believed to consist of organisms, identity unknown

by Lionel A. Walford

THE most useful modern instrument in a pilot house is the echo sounder, which measures the depth of the water automatically and continuously as the ship plows ahead at full speed. The machine sends sound waves into the water, receives the rebounding echoes, translates the intervening time into fathoms and with a stylus draws on a moving strip of paper a graphic picture of the sea bottom, called a bathygram. The echo sounder in effect "sees" the bottom. It sees, also, any other things in the water that can deflect the sound and send back echoes, which means anything whose density is in contrast to that of the surrounding or adjacent medium. This, for example, is what made it possible for the salvage ship *Orphir* in 1935 to perform what was then the spectacular feat of locating the *Lusitania* at the bottom of the North Sea. There the echo sounder spotted a sunken object; it showed that the object was hollow and was 780 feet long and about 84 feet high—which were the dimensions of the *Lusitania.*

Fishermen have been using echo sounders to locate schools of fish since early in the 1930s. They can spot them down to depths of 90 fathoms or more and save themselves untold time over the older method of blind scouting. Under favorable conditions some experts can even tell from the record what kind of fish is below. In places where rivers empty into the sea, as at the mouth of the Mississippi, the echo sounder picks up the boundary between fresh water and salt. It will record a layer of colloidal silt overlying the true bottom, as well as the bottom itself. The sound penetrates the bottom, and the echo sounder will show substrata for a considerable distance beneath the bottom. Small wonder that interpreting a bathygram is tricky, and often subject to controversy.

The subject of our story is a "phantom bottom" which long mystified those who explored the sea depths with echo sounders. They often found odd, unexplainable echoes coming from mid-depths. On some occasions these echoes were distinct enough to inspire reports of shoals in places that later investigation proved to be very deep. Recording machines often marked down a record that looked as though echoes were being sent back by a layer of something suspended at depths from 150 to 450 fathoms down, running more or less parallel with the surface for very great distances. This layer sometimes seemed as much as 300 feet thick. Bathygrams showed a record like this lasting all day long. And then at other times they showed no such layer at all.

For a long time this effect was considered a vagary of the instrument—something like static on a radio. Hydrographers called the layer a "false bottom," or, more dramatically, "the sea's phantom bottom." The phenomenon was more or less dismissed in scientific quarters—until World War II.

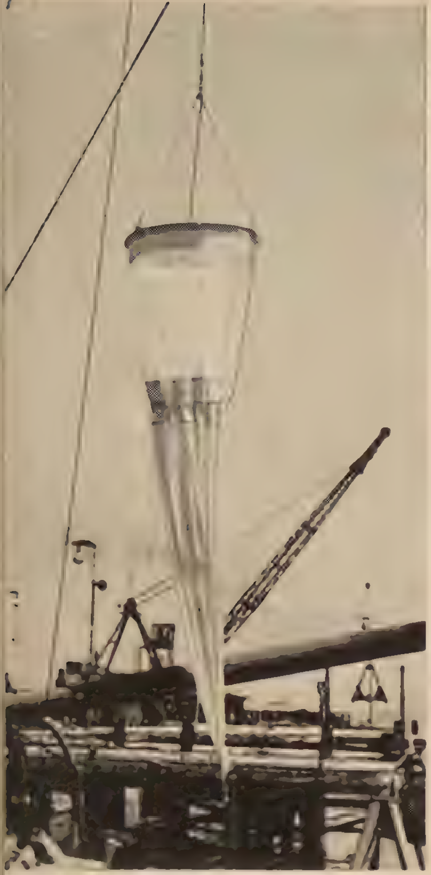
DURING the war the Navy, seeking improvement in the acuity of sounding instruments to help in its battle against submarines, arranged with the Scripps Institution of Oceanography at La Jolla, Calif., to investigate various problems in underwater acoustics. Not long after beginning their studies, scientists working on this project became preoccupied with the mysterious layer. They considered its properties:

It is deep; 150 to 450 fathoms, which means 900 to 2,700 feet, is a long way down. It behaves as though something concentrated there scatters the sound, causing it to reverberate and return many echoes that merge indistinguishably. Those studying it therefore came to call it "the deep scattering layer."

The most fascinating property of this layer was that nearly always it appeared only in the daytime, fleetingly if at all at night. Assuming that the effect was not a peculiarity of the instrument but something in the water, what could it be? One suggestion was that the layer might be composed of inanimate particles of solid matter drifting in suspension, but if this were so, why did it fail to return an echo at night as well as in the daytime?

A more likely suggestion seemed to be that the layer was made up of a mass of living things that somehow migrated at night to upper levels so shallow that the recording of their echo on the bathygram blended with that of the outgoing sound. Three physicists at Scripps Institution, Carl Eyring, Ralph Christensen and Russell Raitt, put this question up to their colleague Martin Johnson, a biologist who specializes in studying the nature and habits of plankton, the mass of drifting plant and animal life that dwells in the sea ("Food from the Sea," by Gordon A. Riley; SCIENTIFIC AMERICAN, October, 1949).

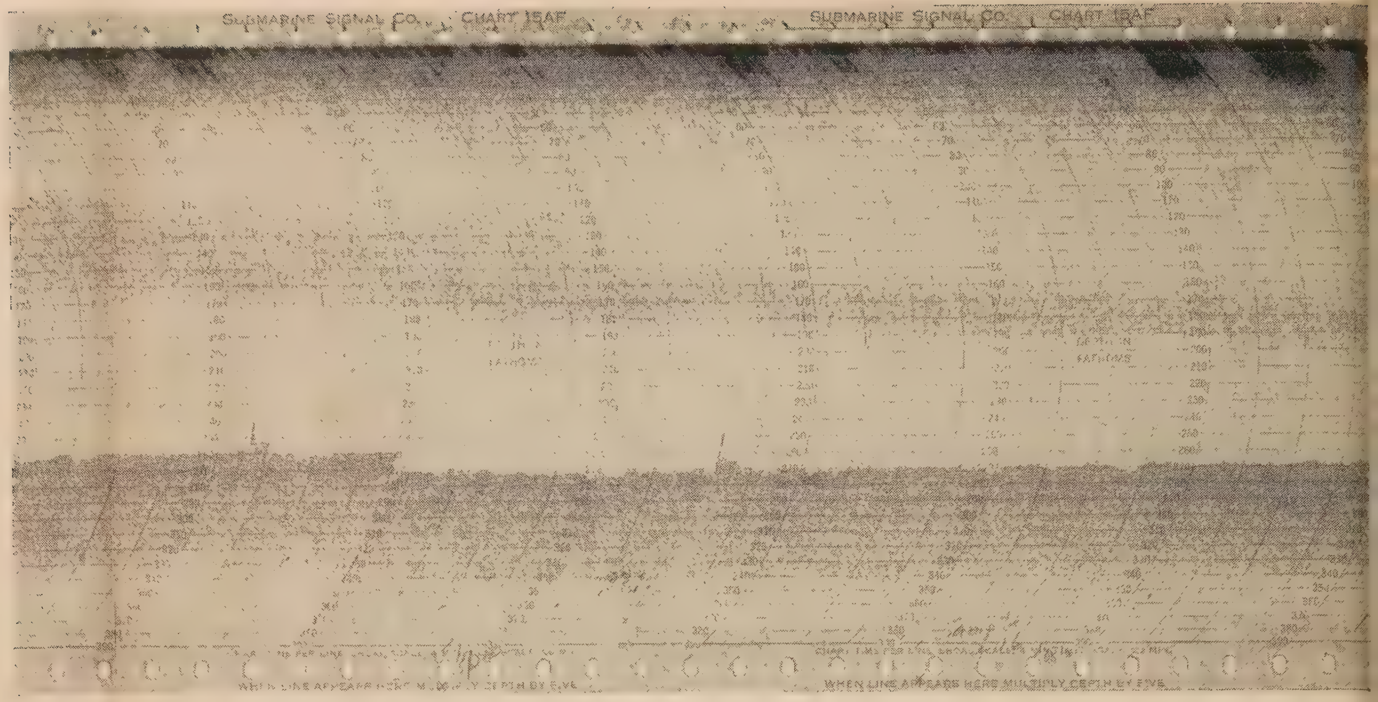
Johnson knew that animals of the plankton migrate toward the surface in the evening and descend again to lower depths in the early morning. Hence it was very possible that plankton might account for the mysterious layer. He suggested a day-and-night watch of the plankton's vertical migrations by echo sounder. On June 26, 1945, Johnson and the three physicists took the research vessel *E. W. Scripps* out about 20 miles off Point Loma, over a submarine canyon



NE-METER NET was used to bring lankton from deep waters to deck f the *E. W. Scripps* last summer.

IX-FOOT NET was also used to atch plankton. It is rigged for openng and closing while in the water.

NET WITH OPENING SIX FEET SQUARE is hung over the side of the *E. W. Scripps.* This oceanographic vessel of the Scripps Institution was cruising in deep waters off San Diego, Calif., when these pictures were made.



THE DEEP SCATTERING LAYER is shown by the faint trace running across the middle of this echo-sounder recording. The stronger trace below it is the bottom of the sea. The depth of the scattering layer is indicated in fathoms by the numbers on the recording. The trace of the bottom, however, has been adjusted so that it is brought closer to that of the scattering layer. Actually the bottom is at the depth shown plus 400 fathoms.

which in some places is close to 4,000 feet deep.

After they had got into deep water, the echo sounder registered a scattering layer about 900 feet down. It remained there all day until evening; then it moved upward at the rate of about six feet a minute until it merged with the surface trace. All night no trace of the layer appeared, but very early the following morning it separated itself from the surface trace on the bathygram and descended to about the level it had occupied the day before.

DURING the two days that the investigator observed the bathygrams, they combed with nets the level where the instrument showed the layer to be located and the regions above and just under it. The nets were the kind of gear generally used for collecting plankton, that is, funnels of fine silk tapering down to a closed bag. They were rigged so they could be opened at the desired depth, and then closed and hauled to the surface without picking up material in other zones.

Johnson and his colleagues caught plankton at all levels down as far as they fished, but not in uniform quantities. The animals tended to concentrate in zones. Those shorter than two millimeters were found in two zones: one within the first hundred yards of the surface, the other in or just under the deep scattering layer. The larger animals, mostly about an inch long, were most abundant at about the level of the layer. Johnson concluded cautiously that "there appears to be some direct correlation of the plankton animals with the scattering layer."

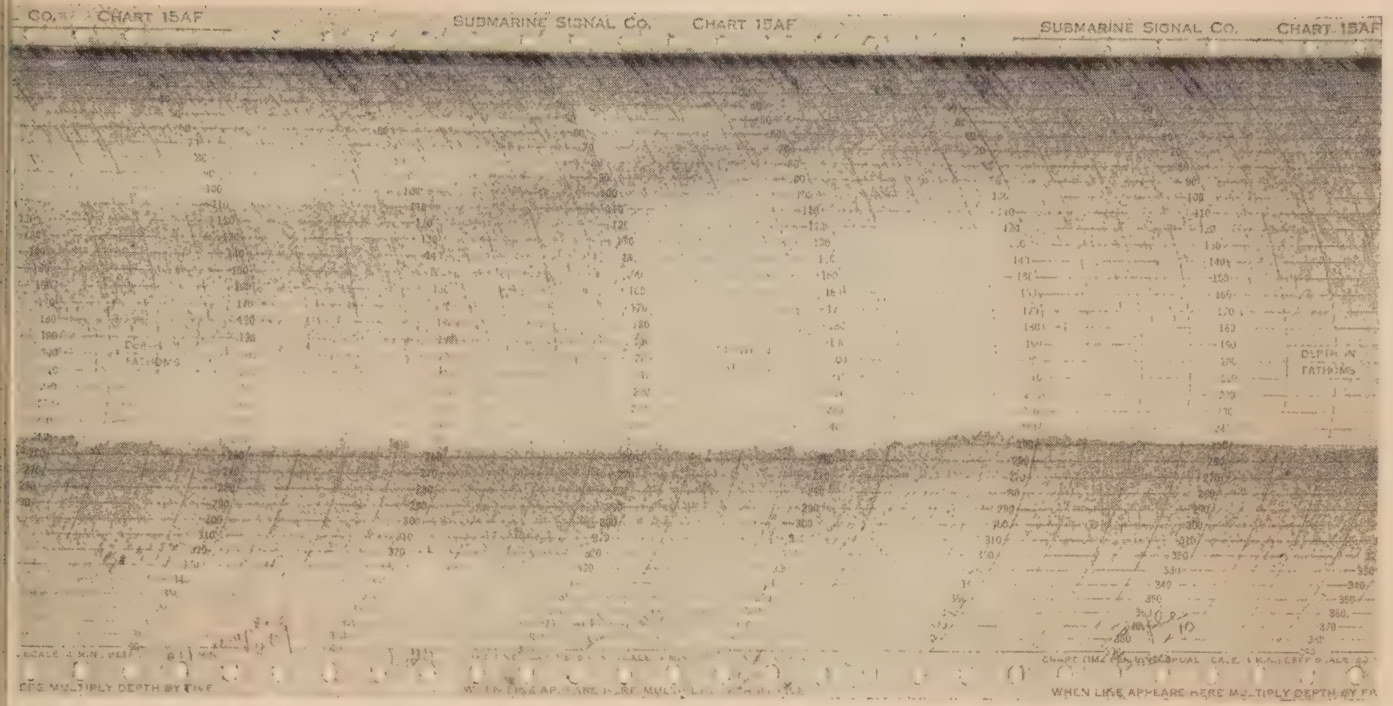
The animals themselves were familiar kinds that had long been known to marine biologists. Most of them were the small buglike crustaceans called copepods. There were some comb jellies, sea-worms and a few euphausiid shrimps, which are the chief food of the whalebone whales. The largest animals were arrow worms, which look like thin rods of colorless, transparent glass.

Were these small-fry the objects that scattered the echo sounder's signals? It seemed doubtful that they had the right acoustic properties, for most of them were too small to scatter sound waves of 18 kilocycles effectively. More likely there were some larger predatory forms down there, too fast to be caught by the nets—large prawns, say, or deep-sea squids. Any of those might be abundant enough to account for the scattering layer.

SINCE that expedition oceanographers have studied echo-sounding records all over the world. They have found the D.S.L. (as they have come to call the deep scattering layer, in keeping with this alphabetical age) to be much more uniformly distributed than anyone had ever believed to be true of plankton. It is widespread throughout the Pacific, Atlantic and Indian Oceans, as well as in the Mediterranean and Red Seas. Conflicting reports have come from the Antarctic. Robert Dietz of the U. S. Navy Electronics Laboratory, who sounded the Antarctic in the U.S.S. *Henderson,* found no D.S.L. during the polar midsummer, a time of continuous daylight, but detected one as the day-night cycle returned toward the end of January. On the other hand, M. P. Tchernia of the French Hydrographic Service on one cruise found the D.S.L. just as common in the Antarctic as elsewhere. This disagreement may be explained by the fact that he used sound of a shorter wavelength than that of Dietz (24.8 kilocycles as compared with 18 kilocycles) and therefore was able to measure organisms too small to be detected by the wavelength Dietz had used.

A. C. Burd and A. J. Lee of the Fisheries Laboratory at Lowestoft, England, have detected layers behaving like the D.S.L. in the comparatively shallow waters (*e.g.,* 240 feet) of the English Channel, the southern North Sea and the Barents Sea near Bear Island. They believe, therefore, that the scattering layer should be called "sonic" rather than "deep."

By now accumulated observations have shown that the scattering layer has the following properties: It is probably universal throughout all seas. It is not a single thing. There is one principal layer which persists at a characteristic depth all day and executes a day-night vertical migration. Other layers may form for relatively brief periods. Some of these may behave like the principal layer, others quite differently. Some layers migrate toward the bottom at night instead of toward the surface; some show no pronounced daily movement. The principal scattering layer itself varies in daytime depth at various places in the



THE SCATTERING LAYER RISES toward the surface at the end of the day. The slight dip at the left end of the scattering-layer trace on the opposite page is the end of its descent at the day's beginning. The trace with which the scattering-layer trace merges at the right is made by the outgoing signal of the recording device. The pencil notations on both pictures were made on shipboard to record events in the exploration of the scattering layer.

world. In very transparent tropical waters, as around Bermuda, it is 1,500 to 2,100 feet down; in less transparent coastal waters, as along the coast of California, it is at 900 to 1,500 feet. Finally, the layers apparently vary greatly in density.

Virtually everyone who has studied the phenomenon believes it to be caused by planktonic animals. But what kind of animals, and how many of them? These questions are still in the realm of speculation, owing to the difficulties of studying plankton. Almost all we can learn directly about plankton depends on what we manage to catch in tow nets. When a biologist hauls a net through a layer of water, he would like to think he is getting a representative sample of all the creatures within the range of his net, but unfortunately a great many things work against his coming close to that ideal.

What happens in the depth when a plankton net drops at the end of a wire and is drawn through the water at a rate of two or three feet per second? What effect does this lumbering, insentient object have on the cosmos down there? Does it stir up a cloud of light in its path as it pushes ahead myriads of the small luminous creatures that inhabit the sea? And as these concentrate in the net, transforming it into a terrifying cone of luminosity, do larger creatures dart out of its way to escape? Then for what distances around the net is the order of things disturbed? Is there any order of things down there or are the components of the plankton only randomly distributed? We can only assume that as the net is hauled through the various swarms of animals, it takes from among them those so unwary, so inagile or simply so unfortunate as to get into it. When it is at last emptied into a pan on deck, how can anyone reconstruct from that chaotic jumble of organisms the pattern of life below? How can anyone know what species and what quantities escaped?

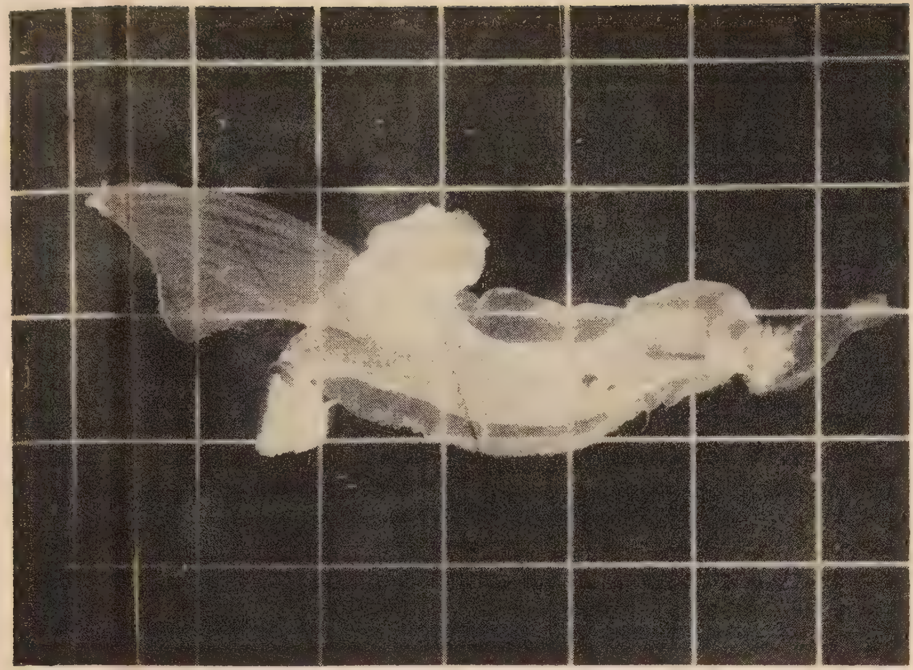
BIOLOGISTS are working to solve these problems. Owing to the tremendous resistance of the water against wire and nets, ordinary plankton nets and small fish-trawls move too slowly to take the fast swimmers. Against this difficulty, several marine laboratories have developed new types of trawls that can be towed faster. But even at best it is still impossible to tell just how representative the catches are.

Meanwhile the literature on the theoretical composition of the scattering layer is growing rapidly. Physicists are trying to identify the scattering animals on the basis of the fact that they must be comparable in size to the wavelength they affect. The method of measurement is to vary the wavelength of the sound signal and observe the resulting variation in scattering. J. B. Hersey of the Woods Hole Oceanographic Institution has developed a method of recording scattering in several frequency bands simultaneously. So far his evidence suggests that there is much variation in the composition of the layers. He believes that the kinds of animals commonly taken in plankton nets (euphausiid shrimps, fish, and so on) can account for the echoes that have been recorded, and that there is probably no heavy concentration of animals longer than about 12 inches in the scattering layer, at least in the Western Atlantic areas where he has been working.

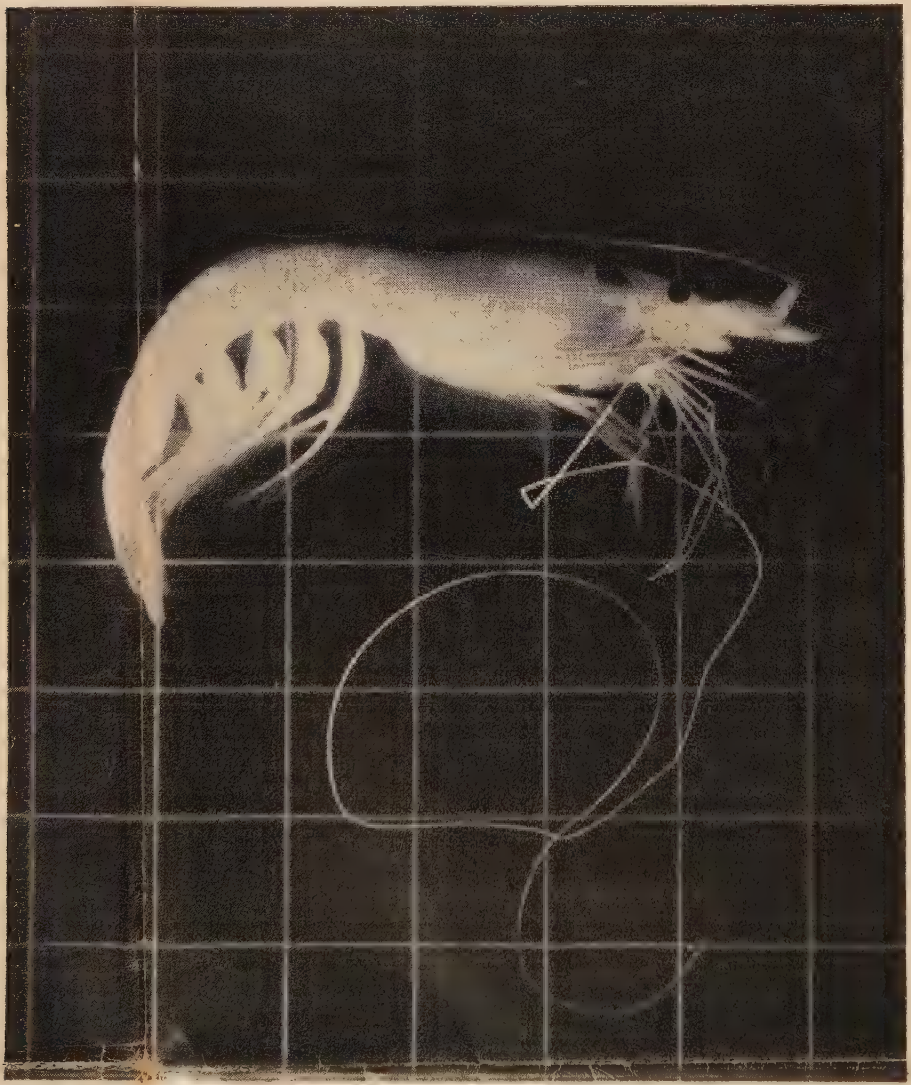
Biologists for their part are considering the question from the viewpoint of what kinds of animals have characteristics that best correspond to the behavior of the principal scattering layer. These are some of the requirements: they must be concentrated by day at depths of 900 to 2,700 feet; they must be large enough and strong enough to swim as fast as six to eight feet a minute; they must be ocean-wide in distribution; they must have some physical structure that reflects sound, such as a swim bladder, gas bubble, oil globule or hard skeleton.

Hilary Moore of Miami University finds that euphausiid shrimps, which are the dominant crustacean at the depths of the principal layer, best meet the requirements. Brian Boden, fishing in the scattering layer with plankton nets off the California coast, caught these animals more consistently than anything else. He believes that these creatures, "or organisms intimately associated with them," may well be the cause of the sounding echoes.

What kind of organisms might those others be? Fish, perhaps. Boden, like everyone else who has worked in the Pacific, noticed the ubiquitous sauries. These little fish, which grow to be 12 to 14 inches long and look like very slender mackerel, appear at the surface at night almost anywhere in the Pacific that one



HETEROPOD, a mollusk with an almost vestigial shell and a foot that has been modified into fins, was brought up from the deep waters of the San Diego Trough. The lines of the grid in the background are half an inch apart.



SHRIMP was also brought up from the waters of the San Diego Trough. These crustaceans and others like them are characteristic of hauls made at between 1,200 and 1,800 feet. The lines of the grid are half an inch apart.

puts a light over the side of the ship. They seem to be among the most abundant and widely distributed fishes in the sea and might be important contributors to the echoes coming from the scattering layer.

Then there are the hundreds of species of grotesque-shaped, luminescent deep-sea fishes, many of which inhabit the deep water by day and rise toward the surface at night. Gordon Tucker, working on the *E. W. Scripps* off California, estimated from his catches that there were as many as 20,000 to 40,000 of them concentrated in the part of the layer within the cone of sound sent down by his echo sounder.

John Lyman of the U. S. Hydrographic Office argues very cogently that the sound scatterers may also be squids. In other words, they can be, and probably are, many of the creatures composing the plankton.

YET all the evidence that has been amassed satisfies no one. Oceanographers continue to discuss the deep scattering layer as an unsolved mystery. And so I believe it will remain until some way is found to look at it in its abiding place. It is 17 years since William Beebe published his book *Half Mile Down*, describing the descent that he and Otis Barton made in the deep water off Bermuda. They went down 3,028 feet in a spherical steel diving chamber which they called a bathysphere. Through its fused quartz windows, three inches thick, they peered at such wonders as have never been caught in nets or on lines, and so have not been seen by anyone else. Unfortunately the scattering layer was not known then, and Beebe has given us no useful quantitative observations that bear on the question. He did, however, write: "Every descent and ascent of the bathysphere showed a fauna rich beyond what the summary of all our 1,500 nets would lead us to expect. Bermuda is in the Sargasso Sea, which is accounted an arid place for oceanic life, but my observations predicate, at least, an unsuspected abundance of unknown forms."

Conclusive proof of the reality of this unsuspected abundance is what many people hope for, since it might become a new source of protein food. That hope, vain though it may prove to be, should, even if the search for knowledge alone were not enough, justify finding somehow, somewhere, enough money to make the bathysphere available again to biologists. If the financial and technical means were found to try it, it is even possible that the deep scattering layer might be made visible by television.

Lionel A. Walford is Chief of the Branch of Fishery Biology in the U. S. Fish and Wildlife Service.